Image Biometric Verification in Spatial Frequency Domain

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Acknowledgments

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- CyLab

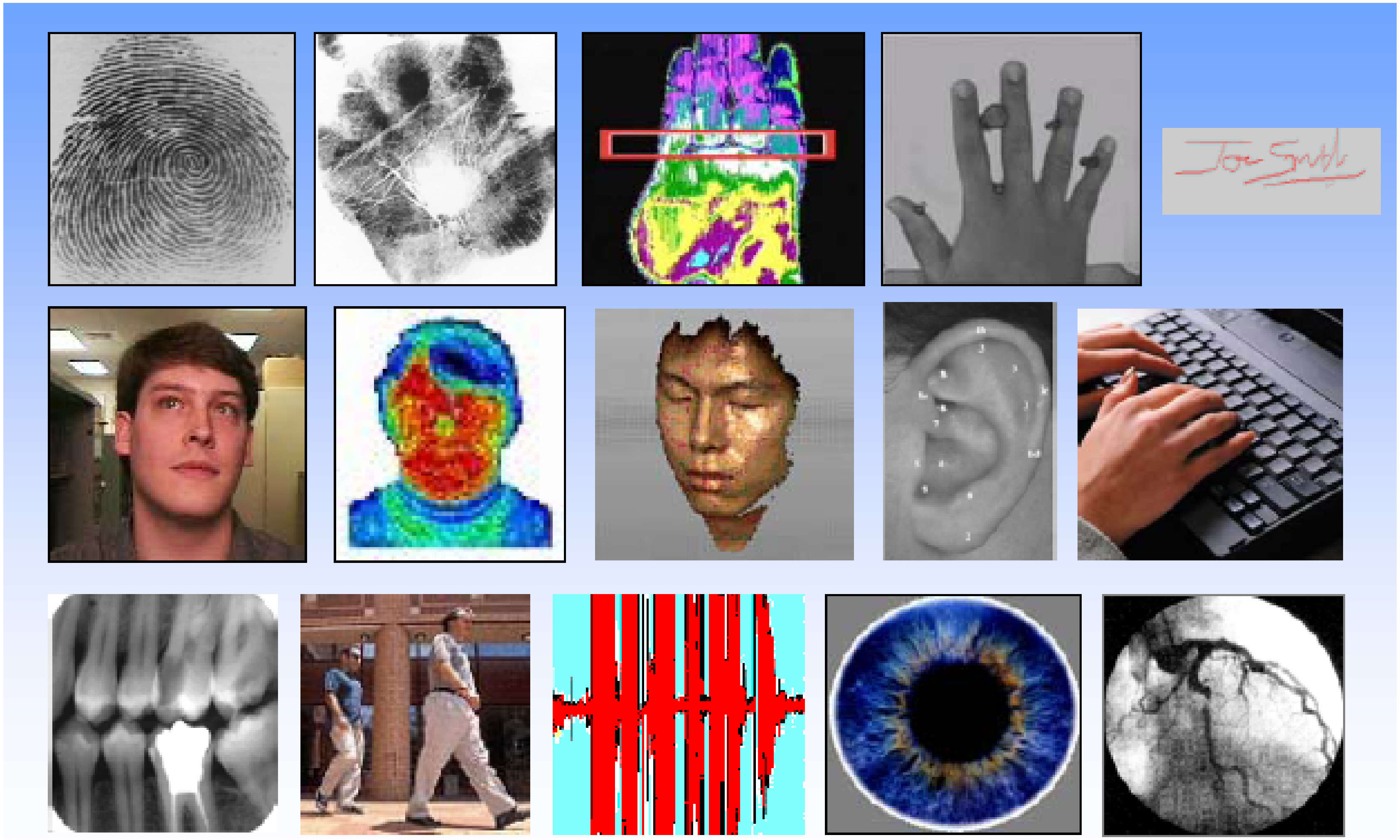
Outline

- Motivation for Biometrics
- Use of spatial frequency domain --- Correlation filters
- Face recognition including face recognition grand challenge (FRGC)
- Iris recognition including iris challenge evaluation (ICE)
- Fingerprint verification
- Palmprint verification
- Cancelable biometric templates
- Conclusions

Motivation

- Recognizing the identity of a person can improve security of access to physical and virtual spaces
- Most current methods rely on passwords ("what you know"), ID cards ("what you have") that can be easily forgotten or stolen
- Identity recognition based on biometrics (e.g., Fingerprints, face, iris, etc.) focuses on "what you are"
- Biometrics: measurable, physical characteristics or behavioral traits used to identify or verify a person

Biometric Types



Courtesy: Prof. Arun Ross

Biometric Applications

Hajj pilgrims in Saudi Arabia

Fingerprint at check-out counter

Disney World

Ben Gurion Airport

Cell Phone with Fingerprint Sensor

Smart gun

Terminology

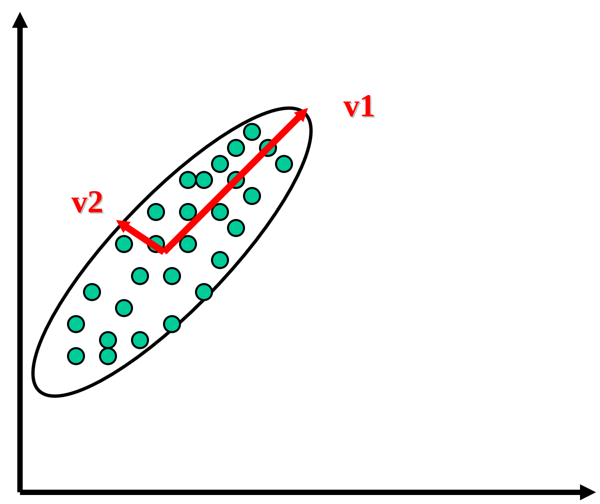
- Verification (1:1 matching)
  - Am I who I say I am?
  - Example application: Trusted Traveler Card, ATM smart card
- Identification (1:N matching)
  - Does this face match to one of those in a database?
  - Example application: Looking for suspects in crowds
- Recognition = Verification + Identification

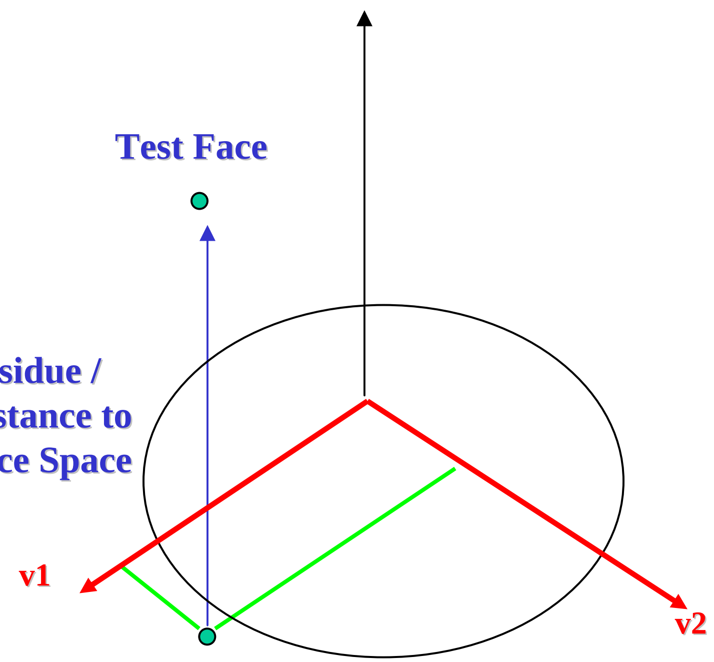
Challenge: Pattern Variability

- Challenge: To tolerate pattern variability (some times called distortions) while maintaining discrimination
- Facial appearance change due to illumination
- Fingerprint image change due to plastic deformation

Eigenfaces

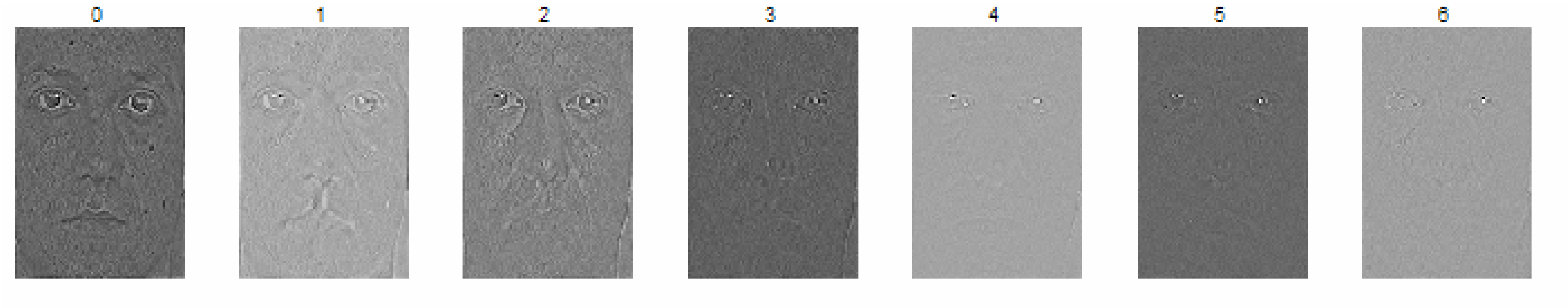
- Each *dxd* image represented as a point in a d^2-dimensional space
- Performs principal component analysis (PCA) on training faces to build a subspace. PCA finds principal directions of variance in training data by diagonalizing the covariance matrix.





Ref: M. Turk and A. Pentland, "Eigenfaces for recognition," *Journal of Cognitive Neuroscience*, 3(1):71–86, 1991

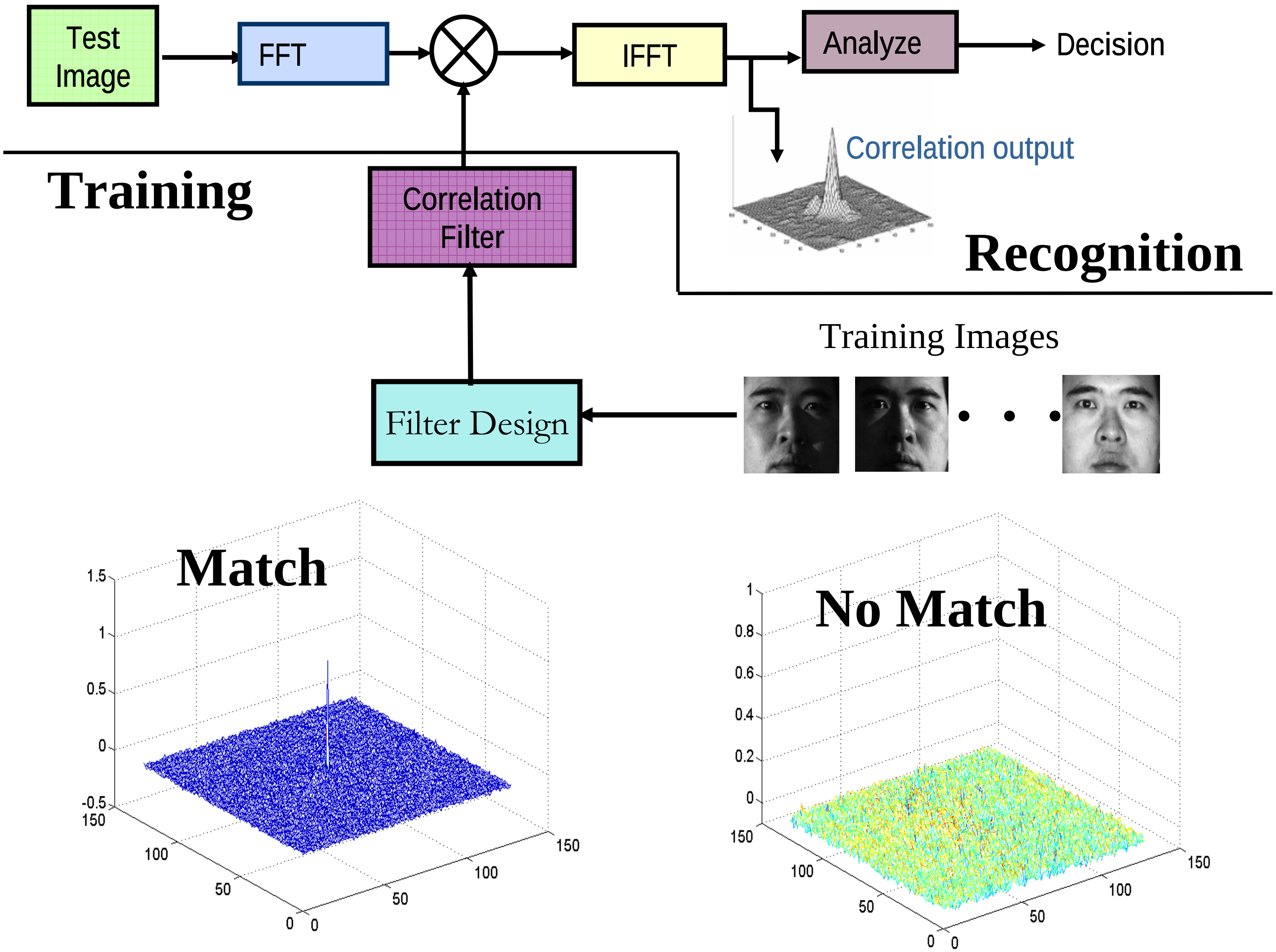
Eigenfaces



- Eigenfaces is an image-domain technique; other image-domain techniques exist
- The 2-D Fourier transform is an information-preserving operation
- Spatial frequency-domain approaches (also called correlation filters) work very well for automatic target recognition (ATR); can biometrics benefit by operating in spatial frequency domain?

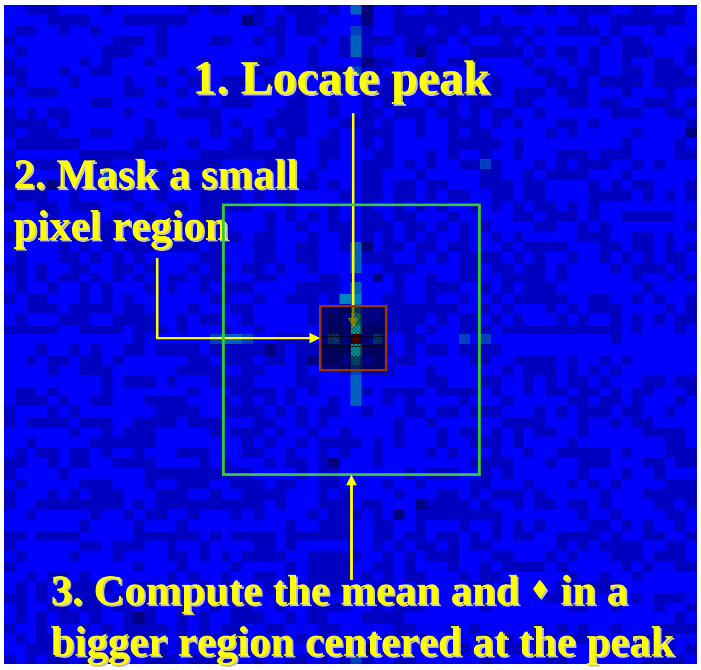
$$F(u,v) = \int\int f(x,y) e^{-j2\pi(ux+vy)} dxdy$$

Correlation Filters



Peak to Sidelobe Ratio (PSR)

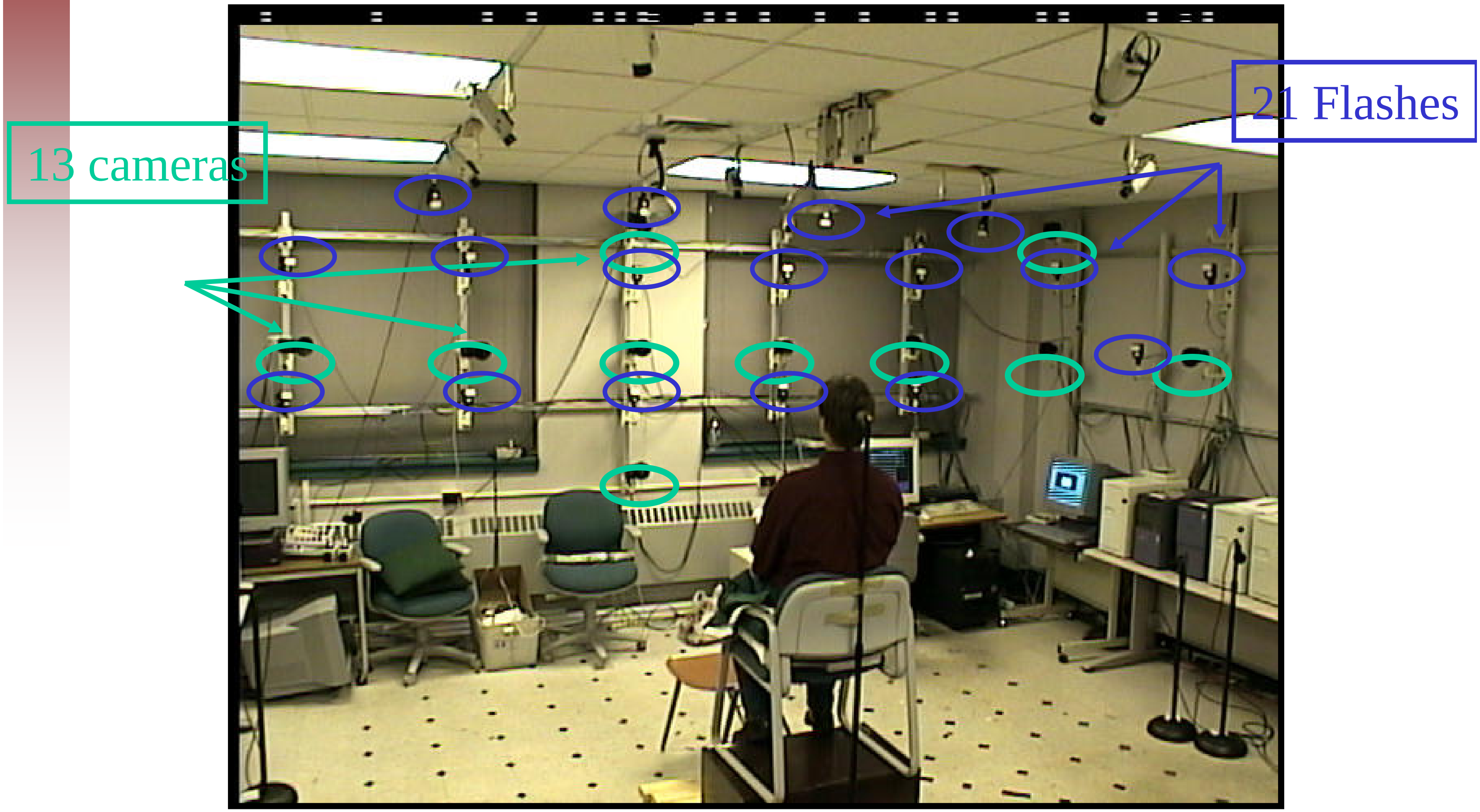
- PSR invariant to constant illumination changes



$$PSR = \frac{Peak - mean}{\sigma}$$

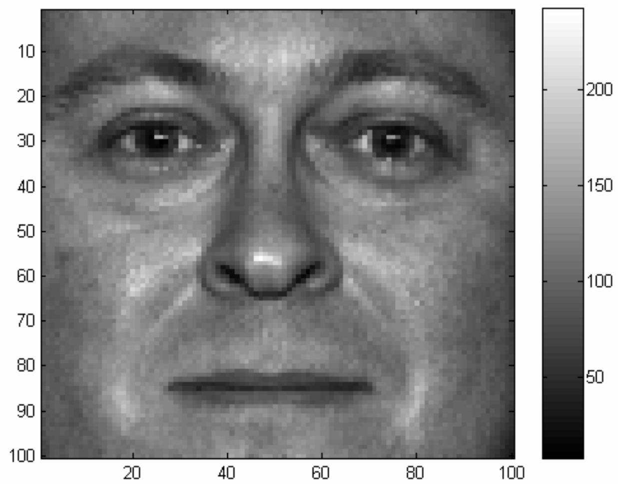
- Match declared when PSR is large, i.e., peak must not only be large, but sidelobes must be small.

CMU PIE Database



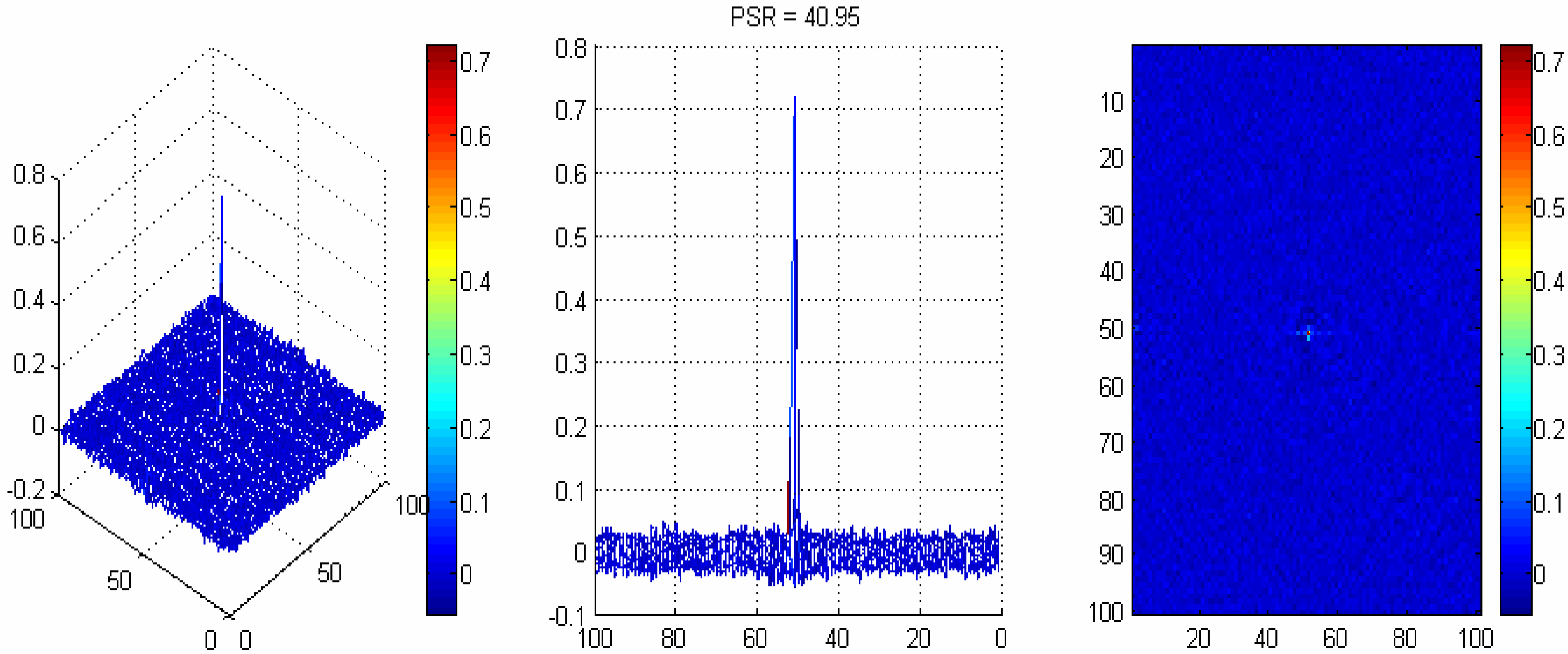
Ref: T. Sim, S. Baker, and M. Bsat, "The CMU pose, illumination, and expression (PIE) database," *Proc. of the 5th IEEE Intl. Conf. on Automatic Face and Gesture Recognition*, May 2002.

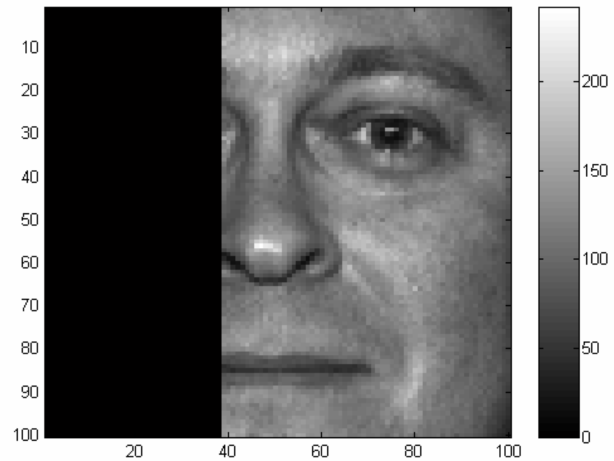
PIE Database, one face under 21 illuminations
65 subjects



Train on 3, 7, 16, -> Test on 10.

Match Quality = 40.95

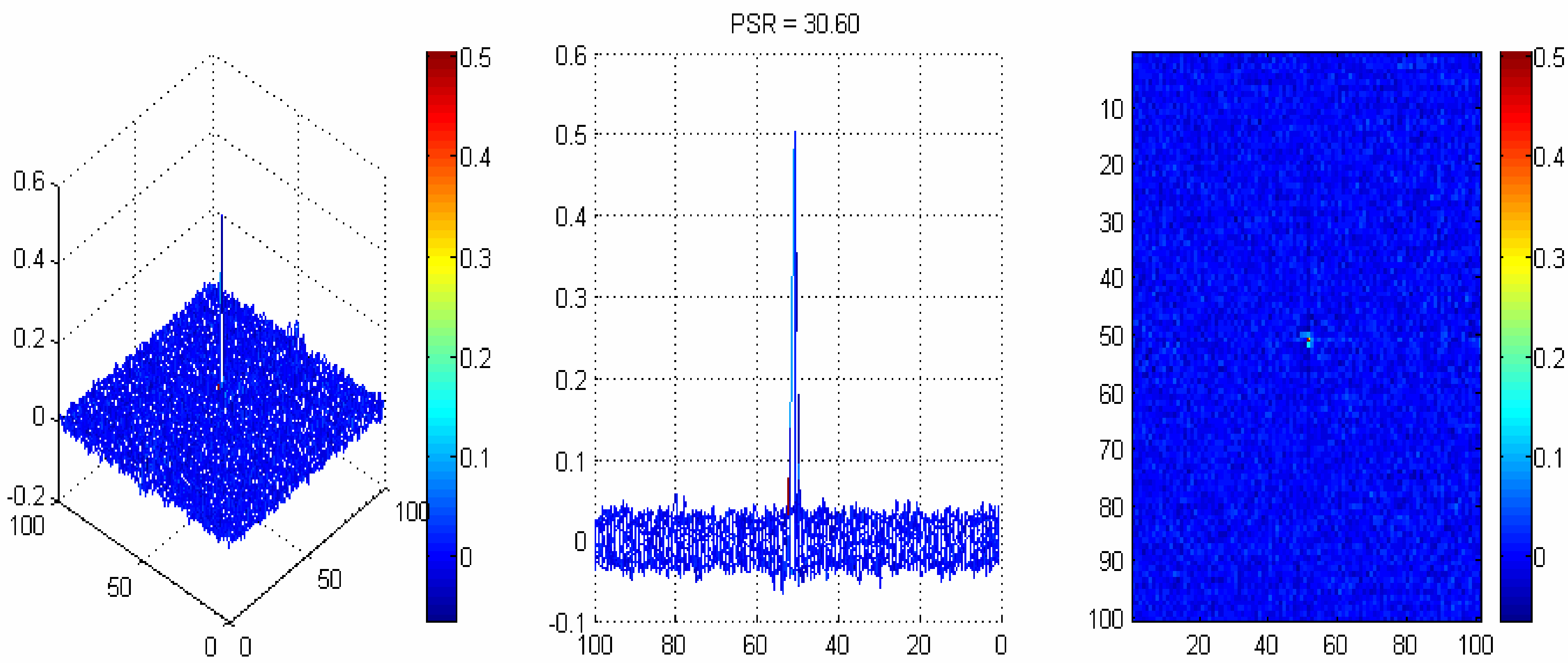


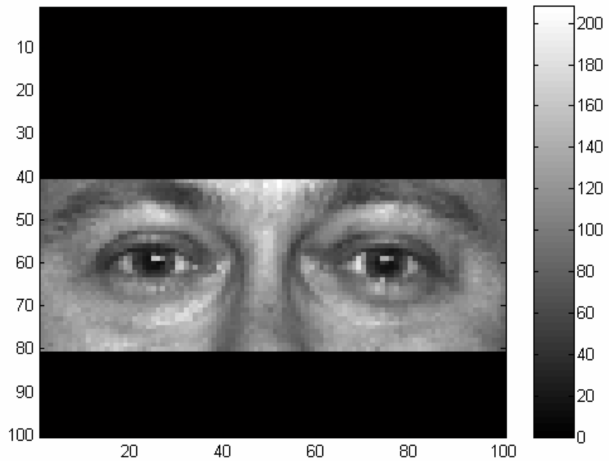


Occlusion of Eyes

Using the same filter as before,

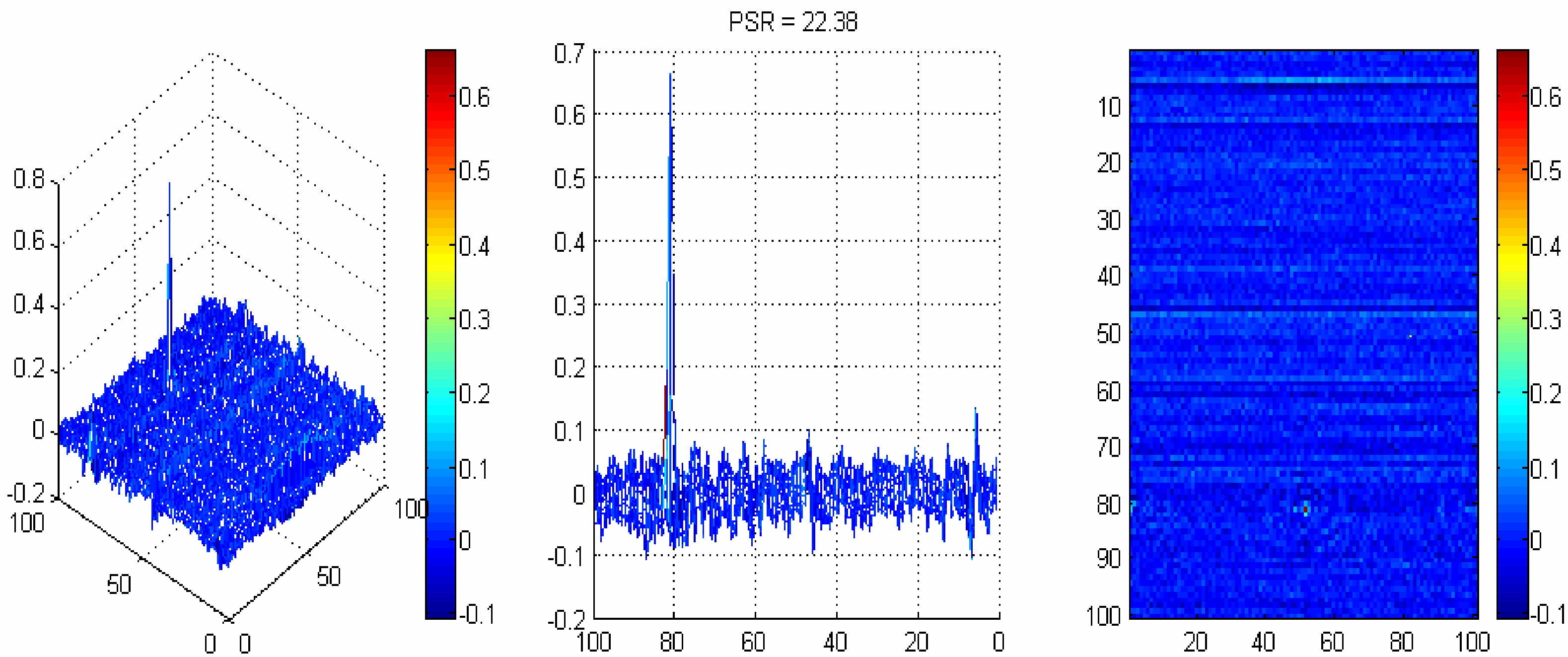
Match Quality = 30.60

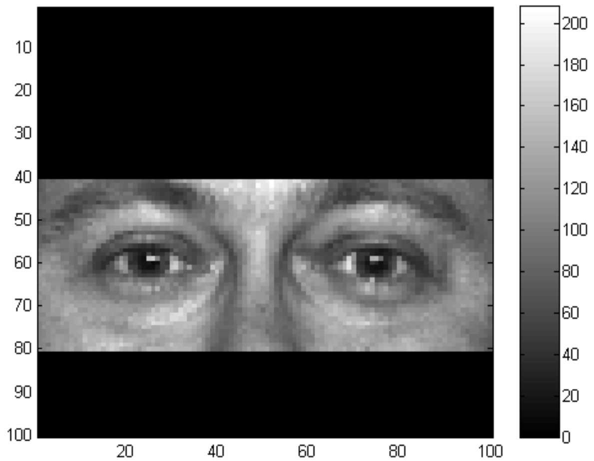




Uncentered Images

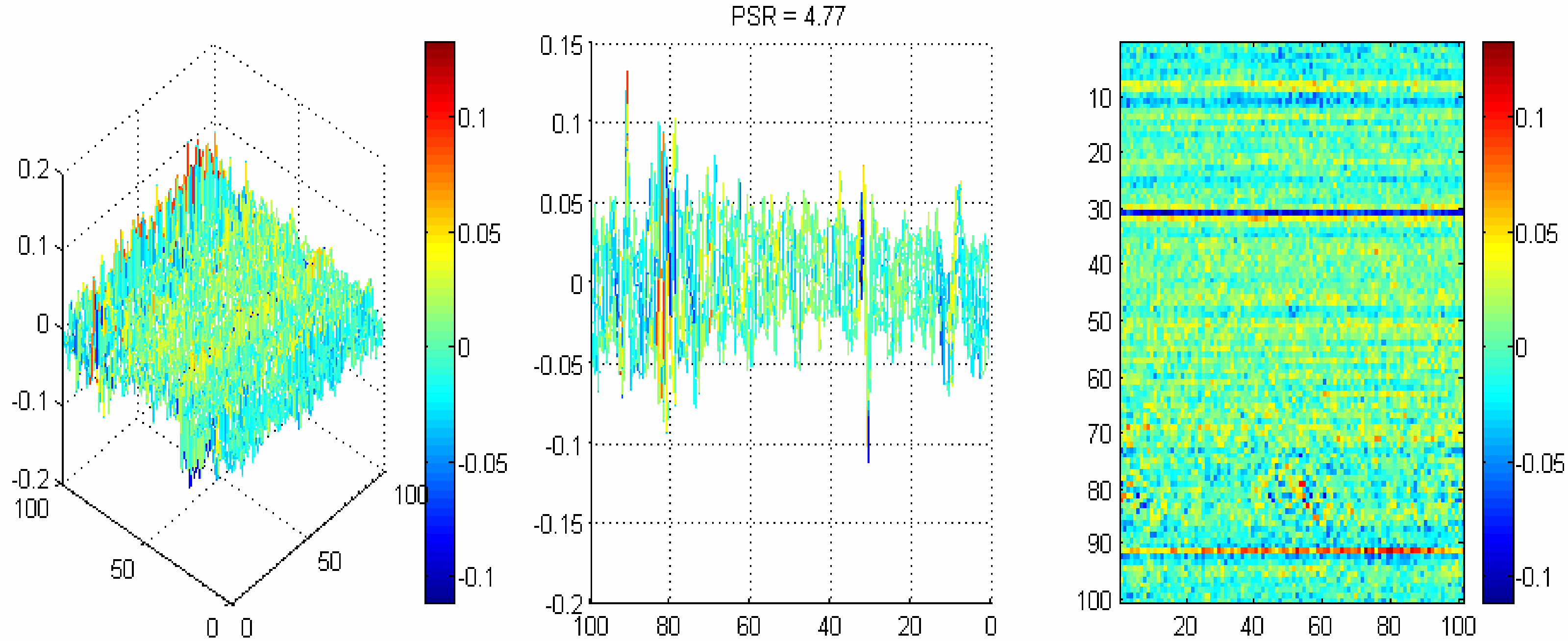
Match Quality = 22.38





Impostor

Using someone else's filter
PSR = 4.77



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Features of Correlation Filters

- Shift-invariant; no need for centering the test image
- Graceful degradation
- Can handle multiple appearances of the reference image in the test image
- Closed-form solutions based on well-defined metrics

Ref: B.V.K. Vijaya Kumar, A. Mahalanobis and Richard D. Juday, *Correlation Pattern Recognition*, Cambridge University Press, UK, November 2005.

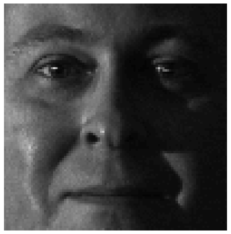
49 Faces from PIE Database with illumination variations

Training Images

- Three face images (dark left half face, normal face illumination, dark right half face) used to synthesize a correlation filter and an individual eigenspace to perform verification

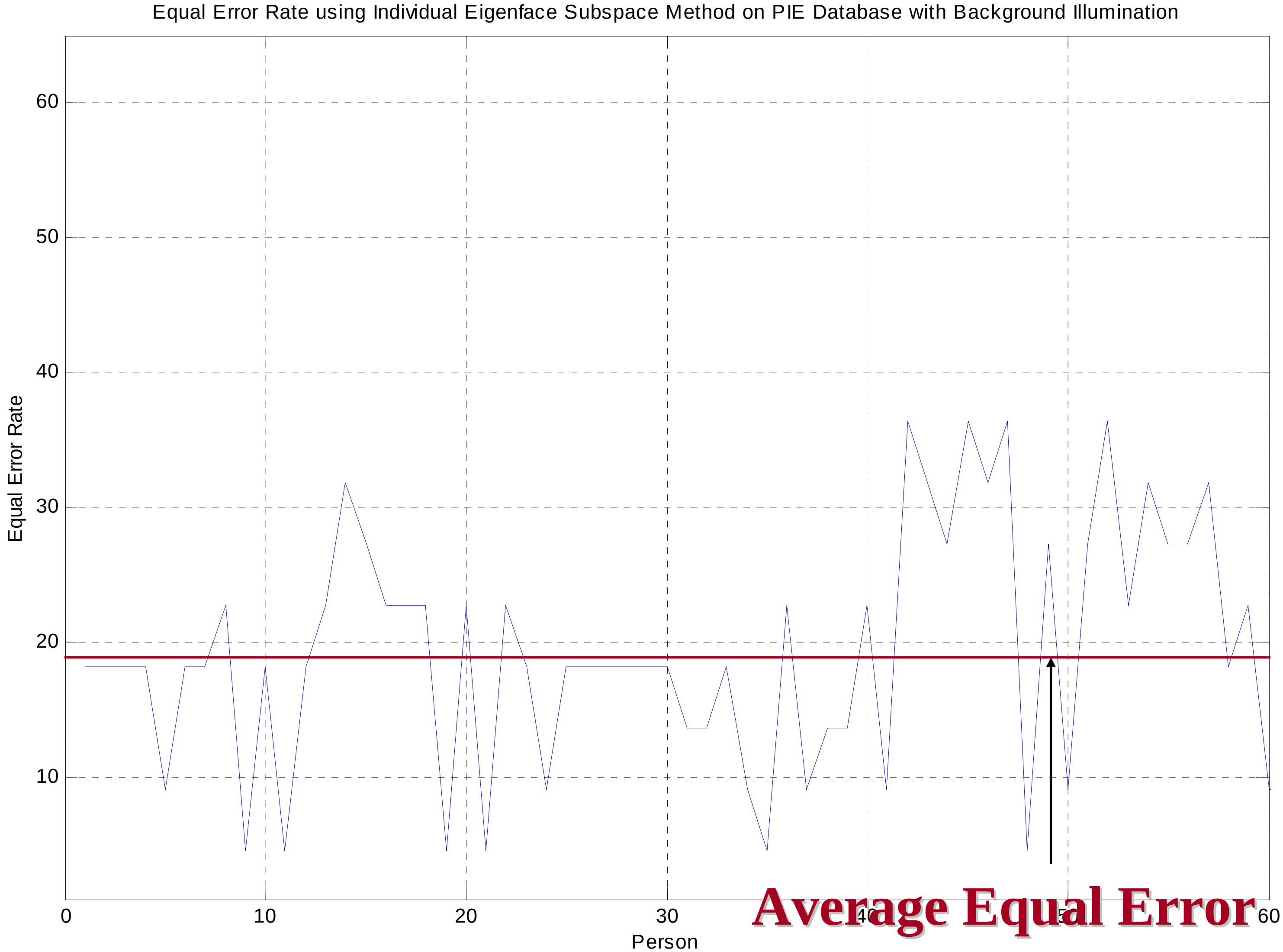
n = 3

n = 7



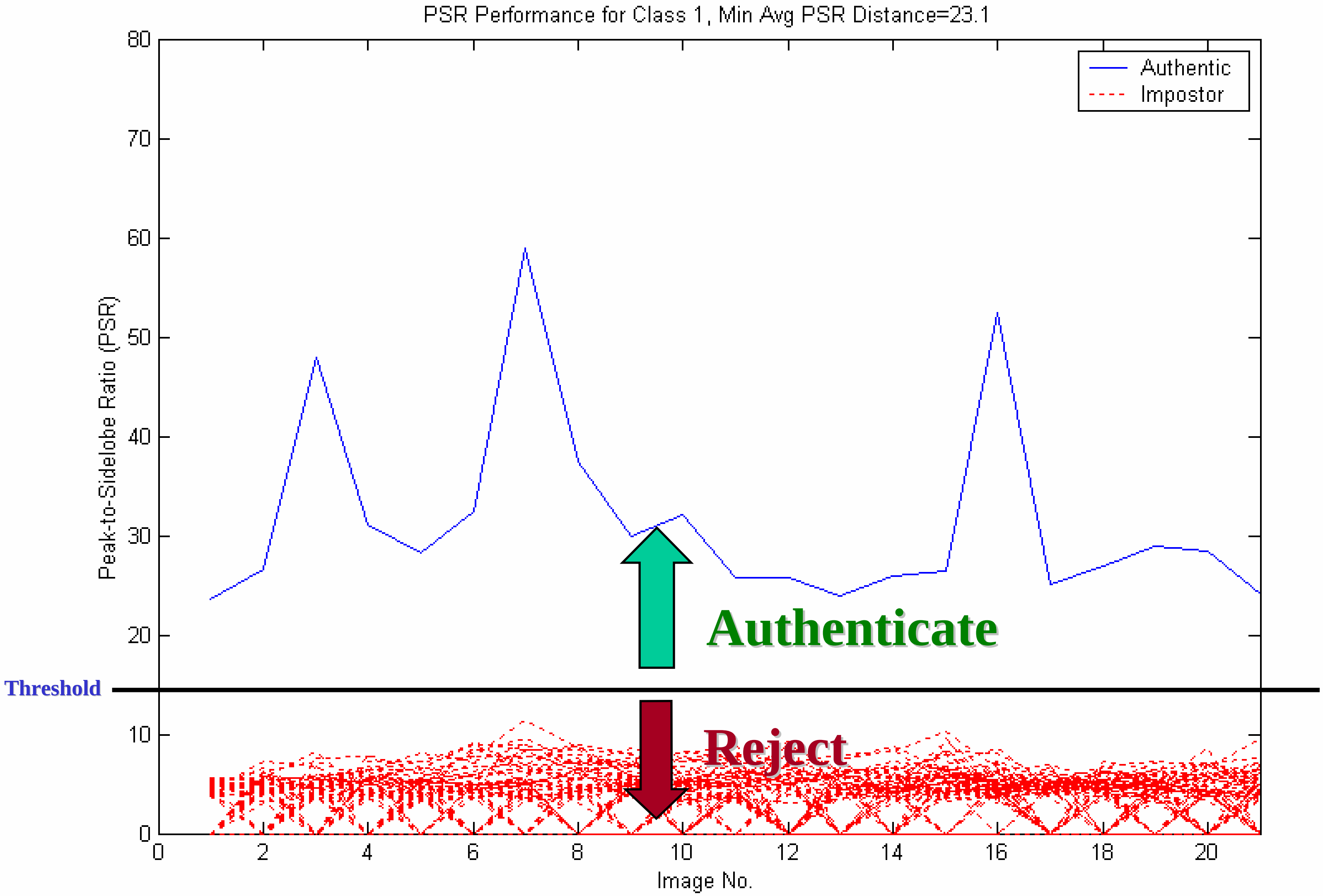
n = 16

Equal Error Rate using Individual Eigenfaces



Average Equal Error Rate = 19.8 %

Peak-to-Sidelobe Ratio using Correlation Filter



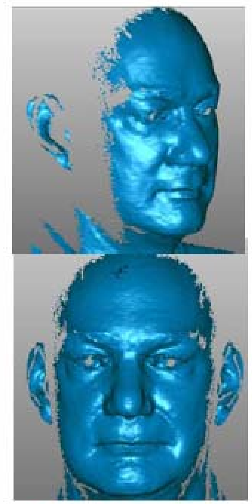
Face Recognition Grand Challenge (FRGC)

- To facilitate the advancement of face recognition research, FRGC has been organized by NIST

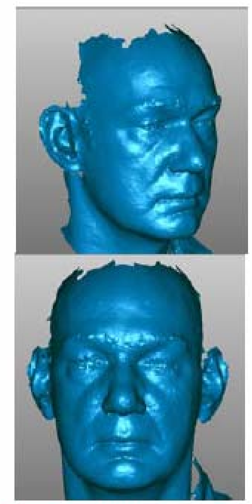
Single Still

Multiple Stills

Outdoor/ Uncontrolled



3D Single view

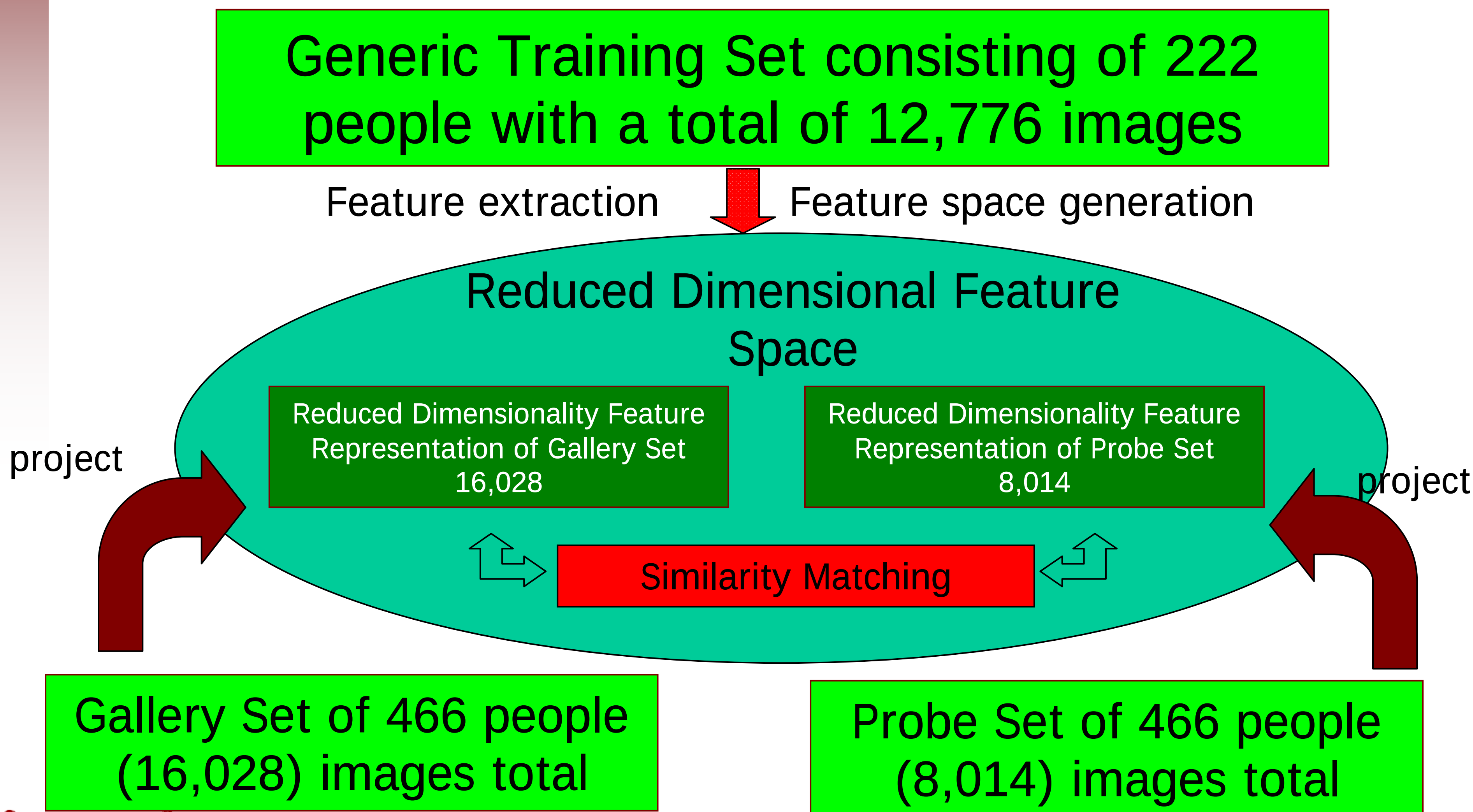


3D Full Face

- Ver 2.0
  - 625 Subjects; 50,000 Recordings; 70 Gbytes

*** P. J. Phillips, P. J. Flynn, T. Scruggs, K. W. Bowyer, J. Chang, K. Hoffman, J. Marques, J. Min, and W. Worek, "Overview of the Face Recognition Grand Challenge,"** ***In Proceedings of IEEE Conference on Computer Vision and Pattern Recognition*****, 2005**

FRGC Dataset: Experiment 4



FRGC "Gallery" Images

Controlled (Indoor)

16,028 gallery images of 466 people

FRGC “Probe” Images

Uncontrolled (Indoor)

FRGC "Probe" Images

Uncontrolled (Outdoor)

Outdoor illumination images are very challenging due to harsh cast shadows

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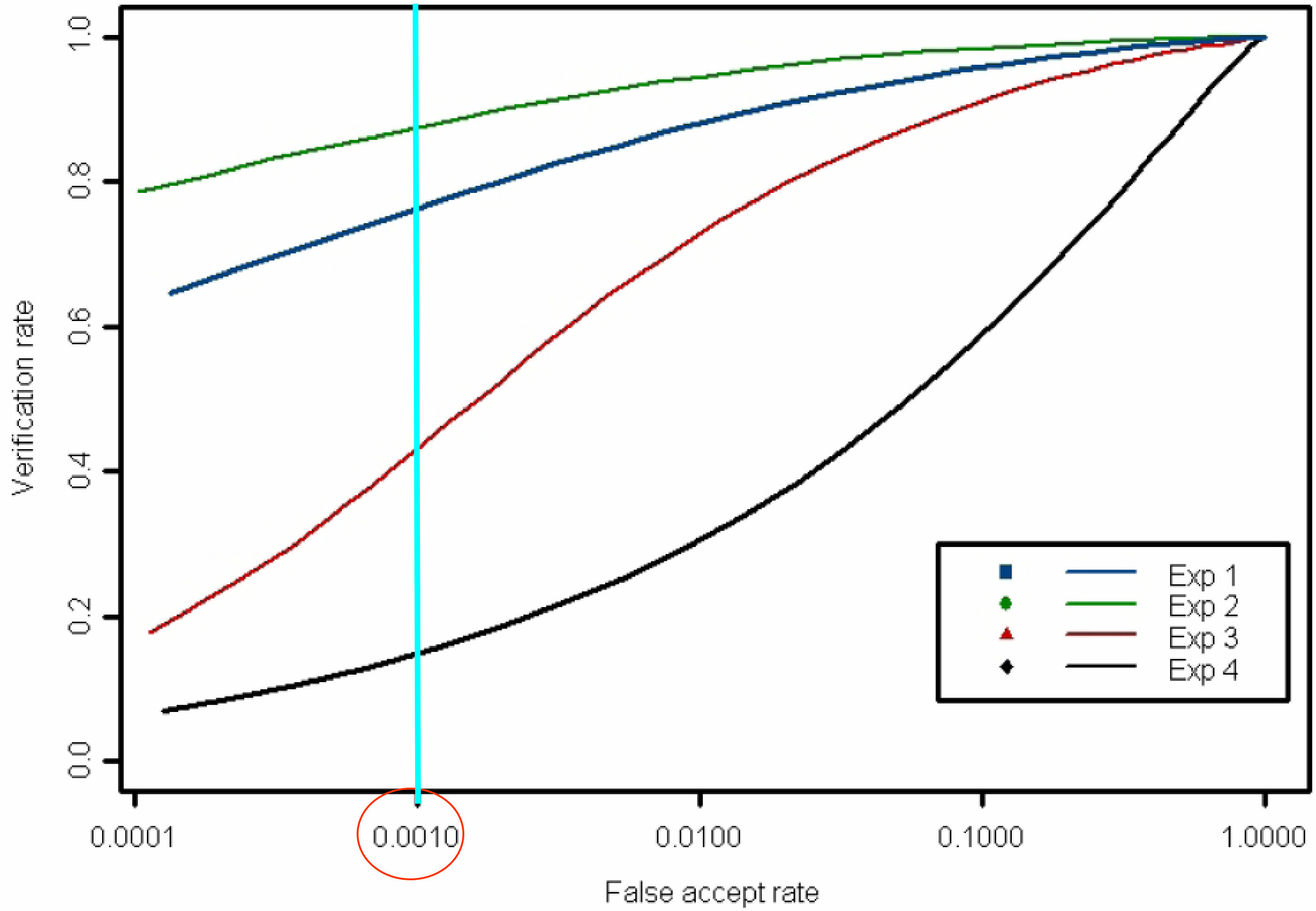
FRGC Baseline Results

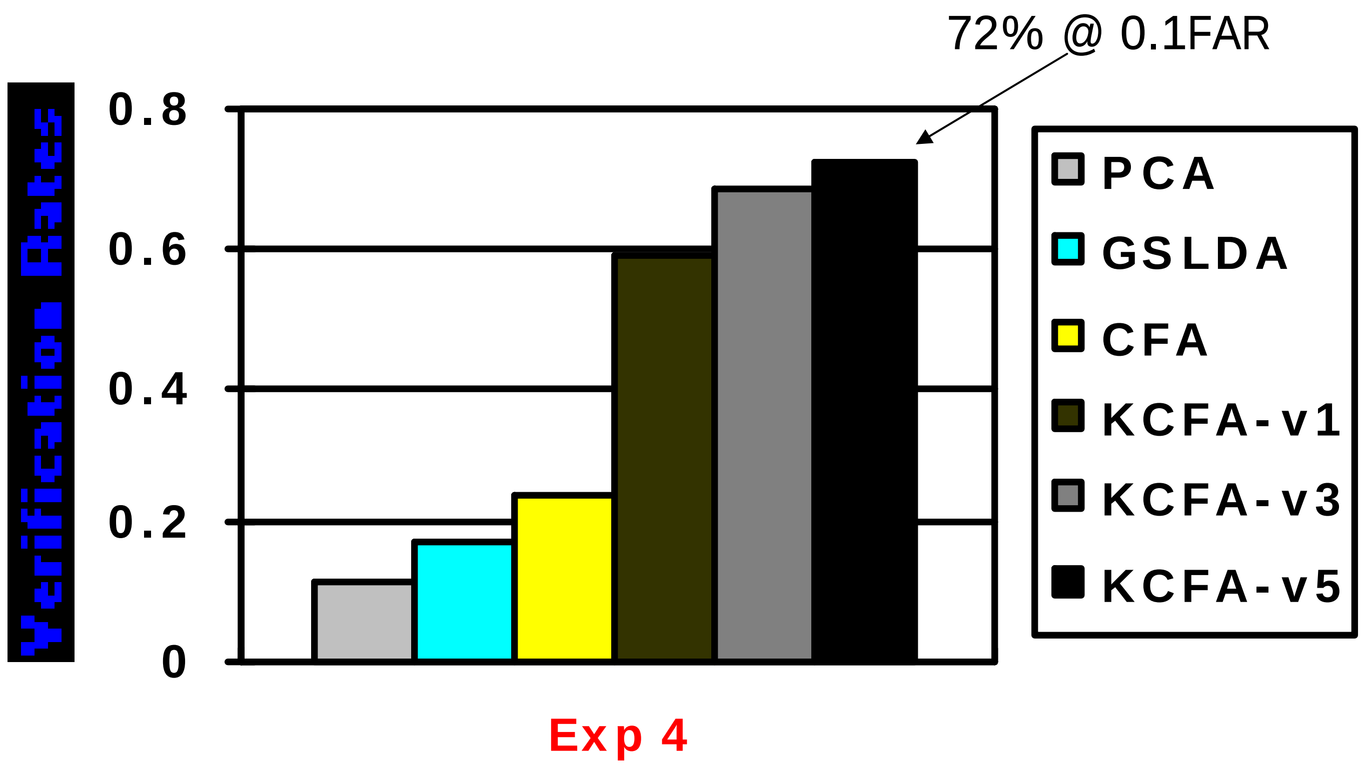


The verification rate of PCA is about 12% at False Accept Rate 0.1%.

ROC curve from P. Jonathan Phillips et al (CVPR 2005)

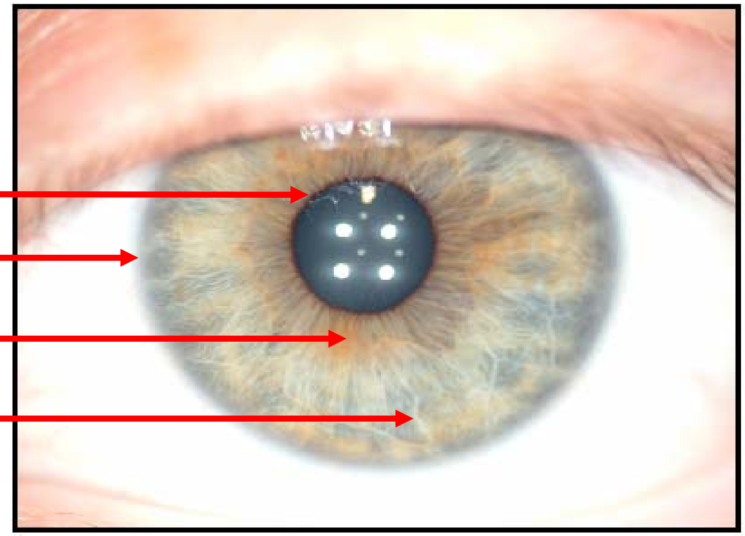
FRGC Expt. 4 Performance

- Eigenfaces (Baseline) results provided by FRGC team
- Performance measured at 0.1 % FAR (False Acceptance Rate)



Iris Biometric

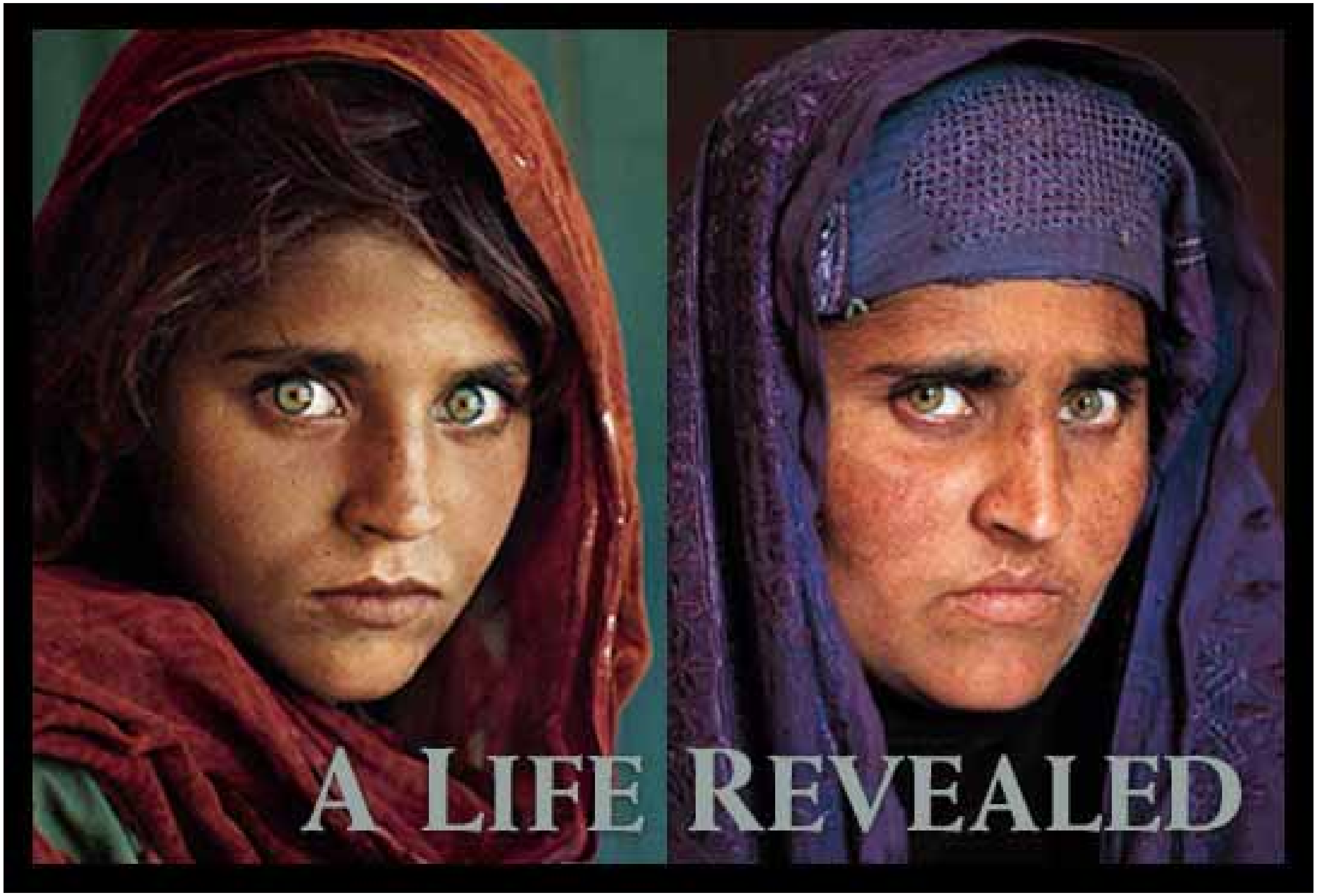
Pattern source: muscle ligaments (sphincter, dilator), and connective tissue



Biometric Advantages

- Extremely unique pattern.
- Remains stable over an individual's lifetime.

Iris Verification



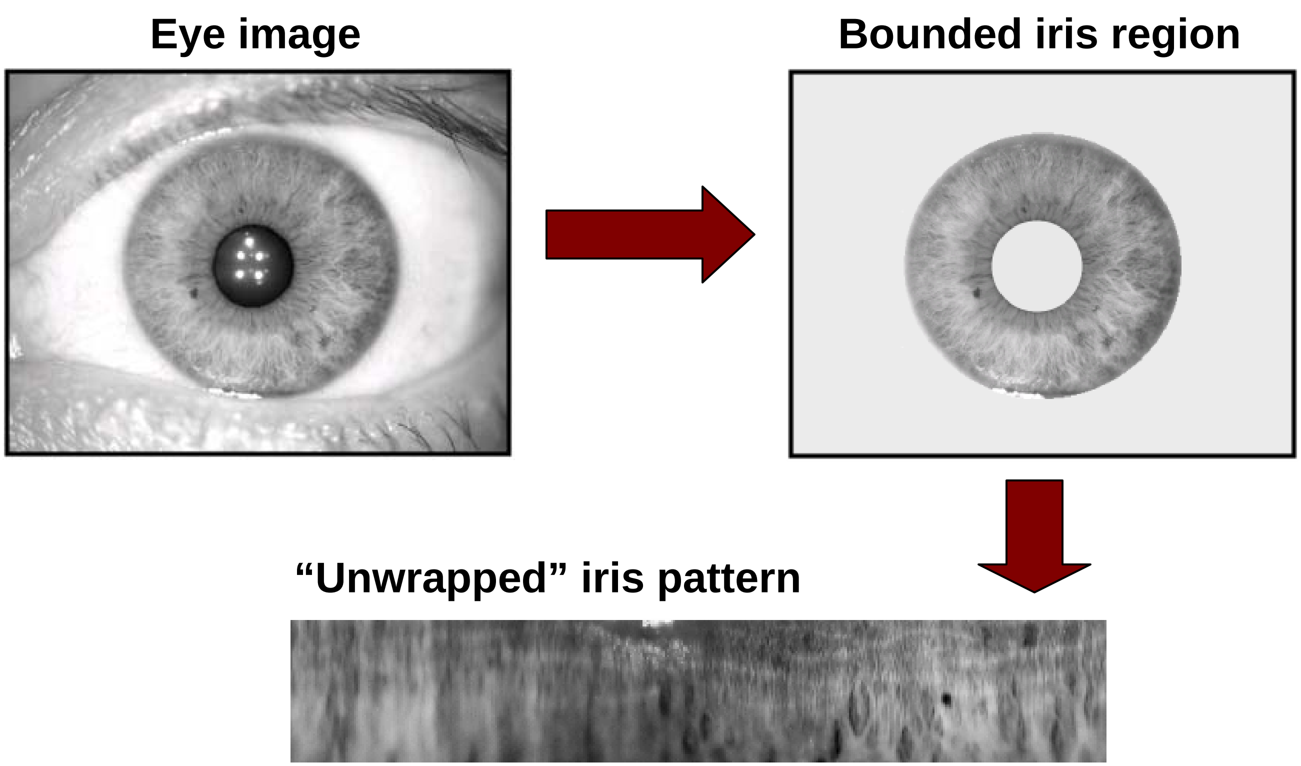
Source: National Geographic Magazine

Iris Recognition System in UAE

- “Largest national deployment so far of iris recognition ... now in its third year of operation.”
- 17 air, land, sea ports; 6500 people/day
- Database of 420,000 iris codes of expellees
- Report zero false matches; 0.2% false rejections
- Daugman, International Airport Review (2) 2004

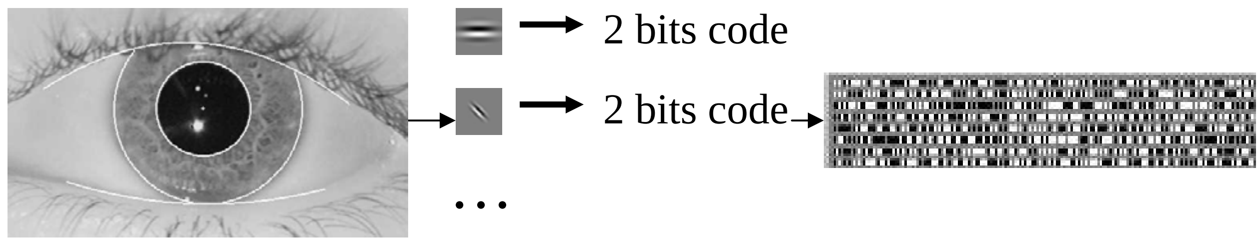
Iris Segmentation

Standard iris segmentation: commonly used, proposed by Daugman[1]



1 J.G. Daugman, "High Confidence Visual Recognition of Persons by a Test of Statistical Independence," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 15, no. 11, pp. 1148-61, Nov. 1993.

Daugman's Iris Code Method



Circular Edge Detector ***Gabor Wavelet Analysis*** ***2048 bits iris code***

- 2D Gabor Wavelet Transform

$$\int_r \int_\theta G(r,\theta) I(r,\theta) r dr d\theta$$

$$G(r,\theta) = e^{-i\omega(\theta-\theta_0)} e^{-(r-r_0)^2/\alpha^2} e^{-(\theta-\theta_0)^2/\beta^2}$$

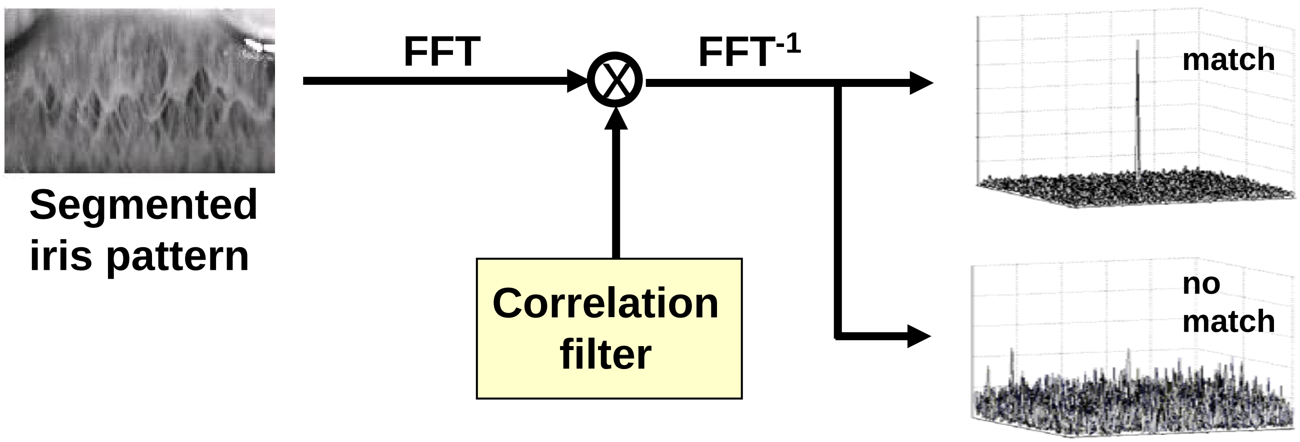
- 5 parameters in Gabor function $\alpha, \beta, \omega, \theta_0$ and r_0
- Hamming distance between iris codes used to decide authentic/impostor

Ref: J. G. Daugman, "High confidence visual recognition of persons by a test of statistical independence," *IEEE Trans. Pattern Anal. Machine Intell.*, Vol.15, pp. 1148-1161, 1993.

Iris Recognition: Correlation Filters

We use correlation filters for iris recognition. We design a filter for each iris class using a set of training images.

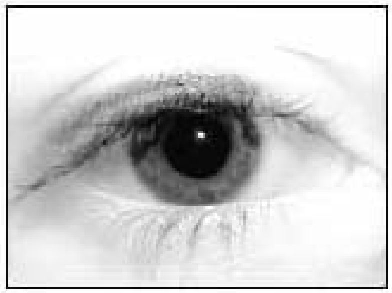
Determining an iris match with a correlation filter



Define Experiments

Exp 1

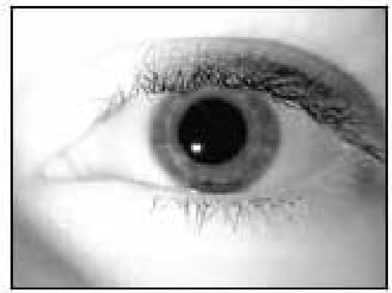
Right Eye



1425 Iris Images
124 Individuals

Exp 2

Left Eye

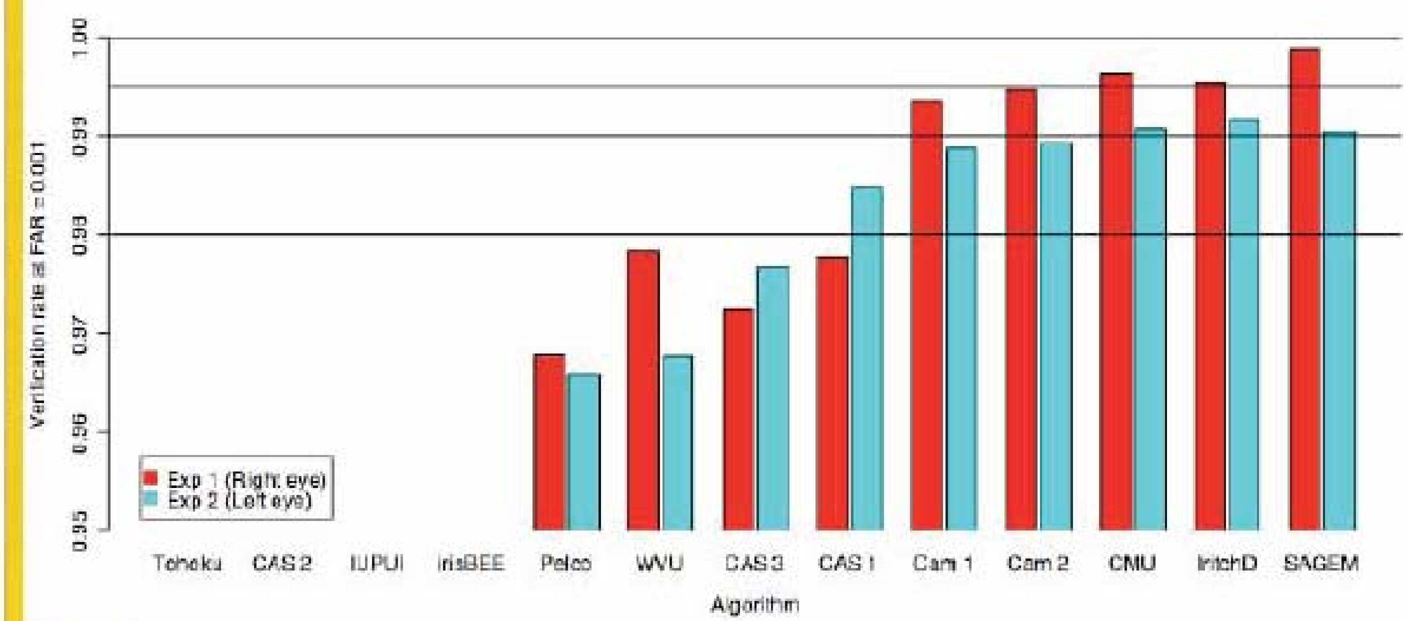


1528 Iris Images
120 Individuals

112 Overlapping Individuals
132 Total Individuals

Source: Jonathon P. Phillips, NIST

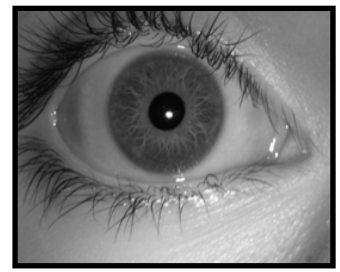
Bar Plot Performance Results Fully Automatic, FAR=0.001



Results from Open Book Challenge Problem
NOT Independent Evaluation

Source: Jonathon P. Phillips, NIST

Iris On the Move (IOM)

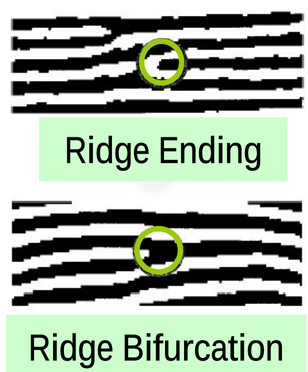


Fingerprint Recognition

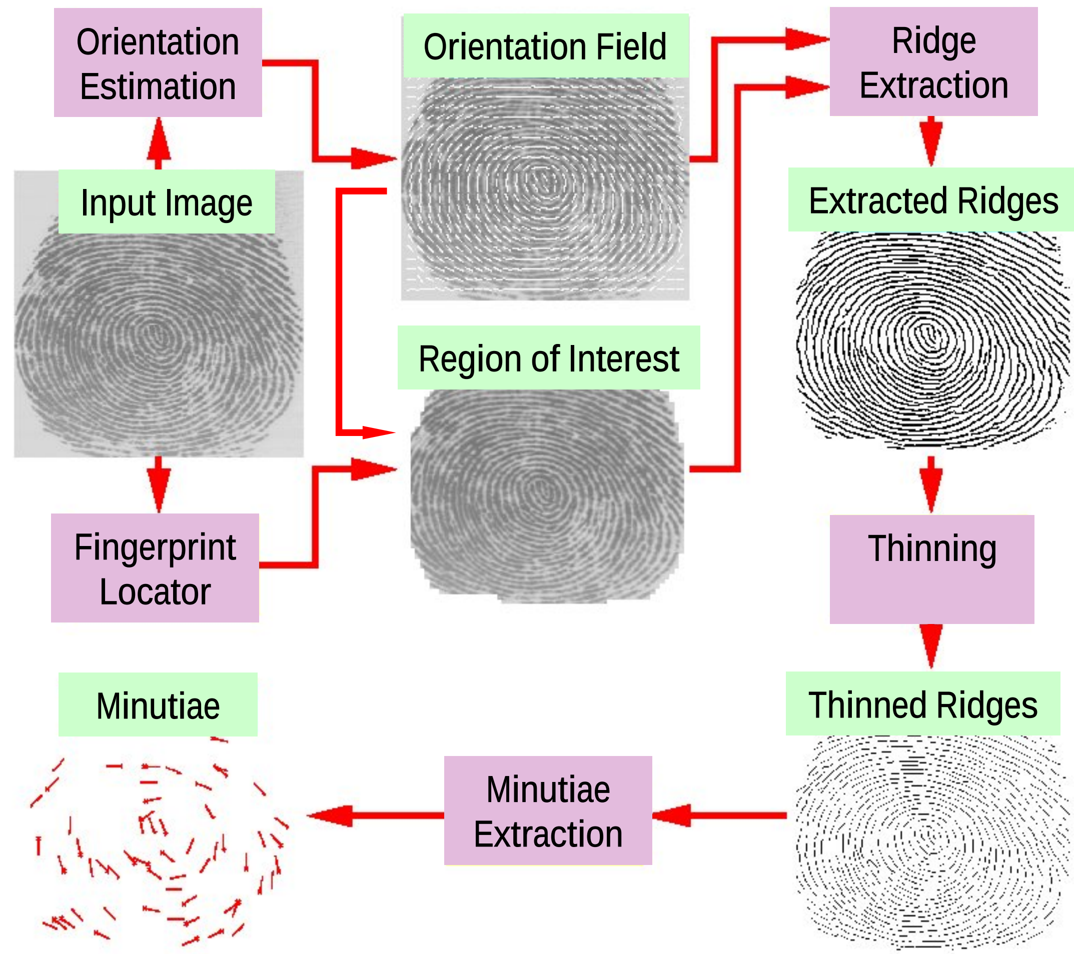
- 1880 – Fingerprint identification in India by Herschel
- Fingerprint identification used in law enforcement
  - Automated Fingerprint Identification Systems (AFIS) FBI Standards
    - Minimum resolution of 500 dpi (inked as well as live scan)
    - Some companies: Bioscrypt, Sagem, etc.
- Current interest – digital live-scan devices
  - Sensors - optical, capacitive, electric-field, thermal, ultrasound
- Access control applications
  - cell phone, PDA, computer, bank ATM, buildings,..

Minutiae Extraction

- Minutiae – ridge endings/bifurcations
- Minutiae extraction
  - Orientation field estimation
  - Ridge extraction
  - Thinning
  - Minutiae extraction



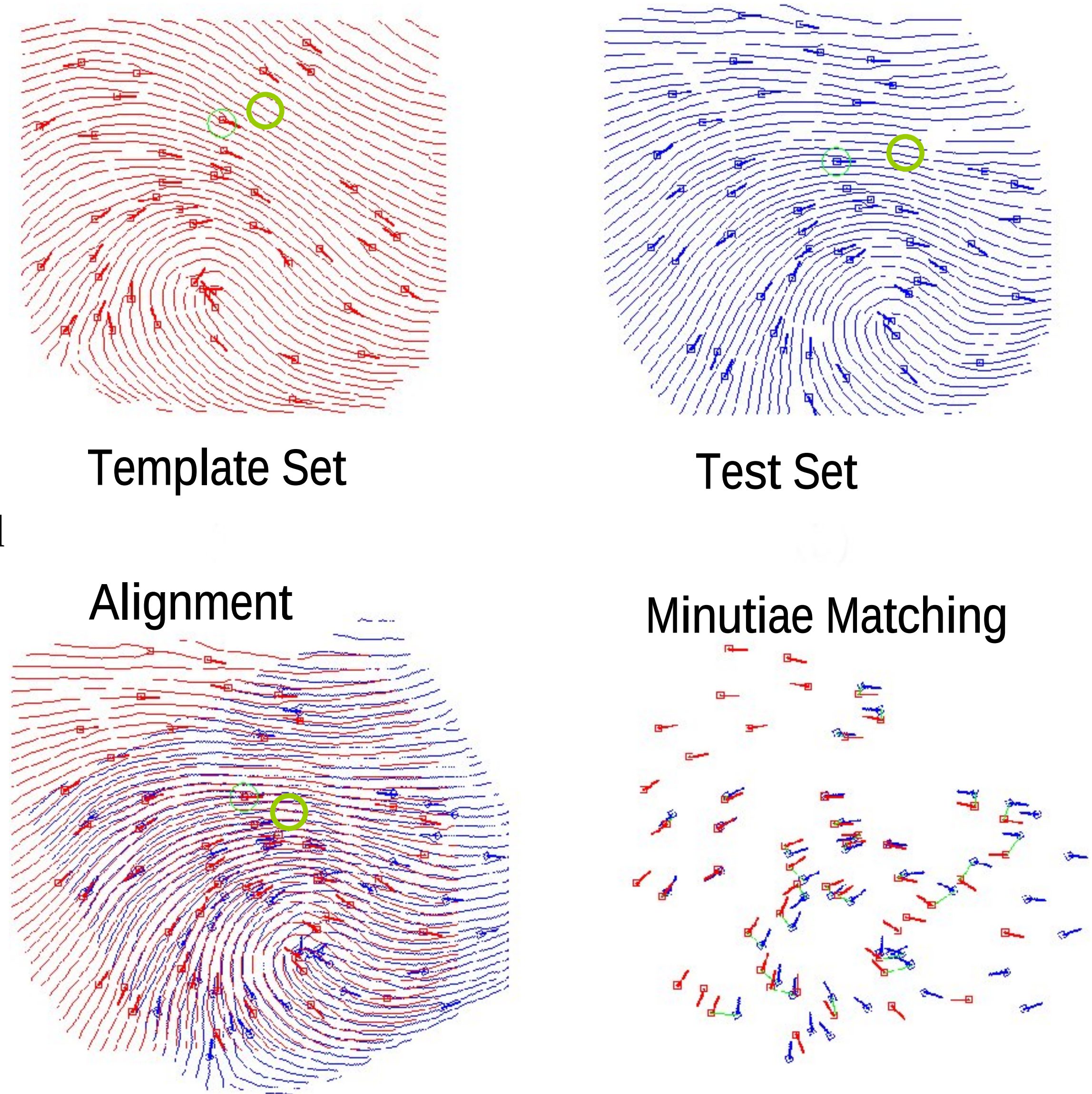
Minutiae



Ref: A. Jain, L. Hong, R. Bolle, "On-Line Fingerprint Verification," *IEEE Transactions on PAMI*, Vol. 19, pp. 302–314, 1997.

Minutiae matching

- Minutiae Matching
  - Find a reference minutiae pair
  - Alignment of template and test sets
  - Minutiae matching by searching around an elastic bounding box



Ref: D. Maltoni, D. Maio, A.K. Jain and S. Prabhakar, *Handbook of Fingerprint Recognition*, Springer Verlag, New York, 2003.

NIST 24 Database

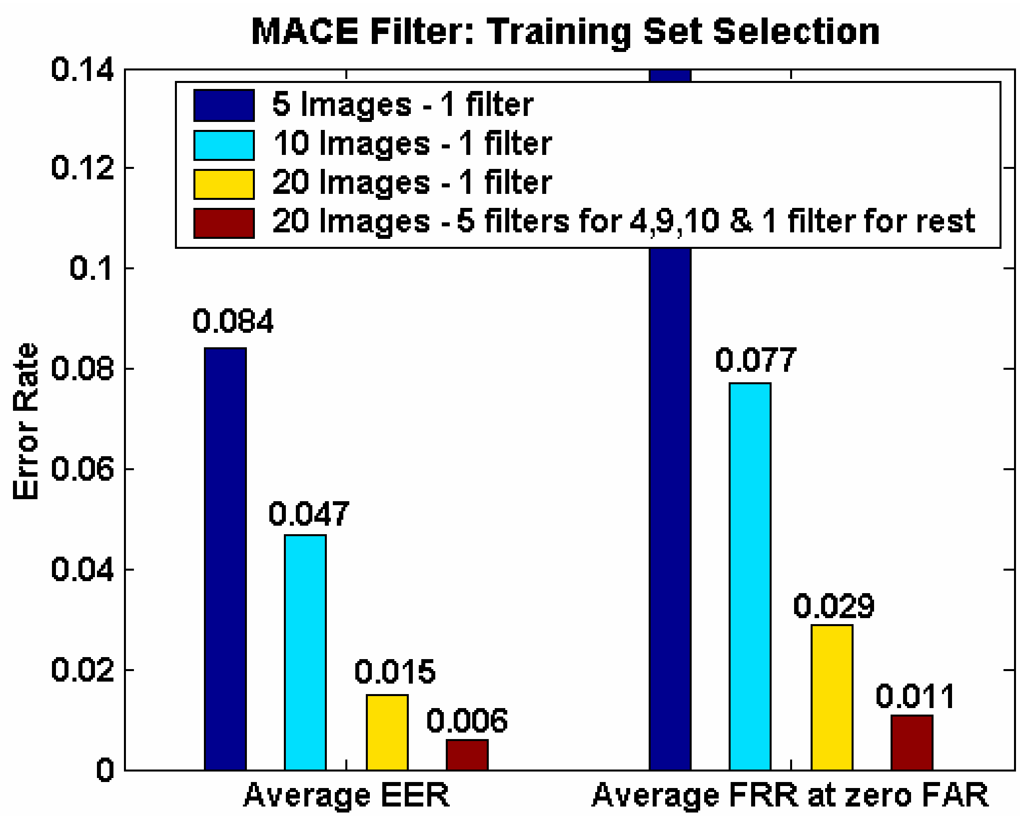
- Digital Video of Live-scan Fingerprint Data
- Optical sensor DFR-90 from Identicator technology of 500 dpi resolution
- Chosen data set - plastic distortion set
  - The finger is rolled and twisted
- 10 fingers of 10 people (5 female and 5 male)
- 10 secs of MPEG2 movie per finger
  - 300 images of size 448x478 pixels (padded to 512x512 pixels)
- Chosen subset - 10 thumb prints

Class 3

Class 10

Evaluation Protocol

- Training - uniformly sampled images from the 300 images of a class
- Test - correlate filters of each class against 300 images of all classes
  - Images of the same class as the filter – 300 authentics per filter
  - Images of a different class from the filter – 2700 impostors per filte



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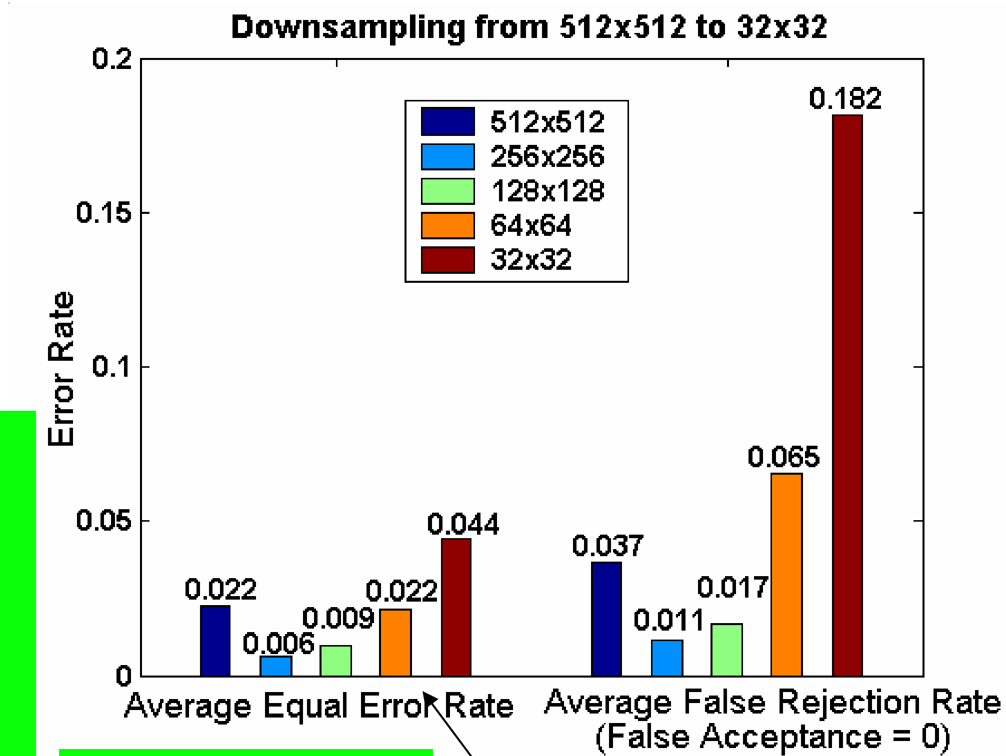
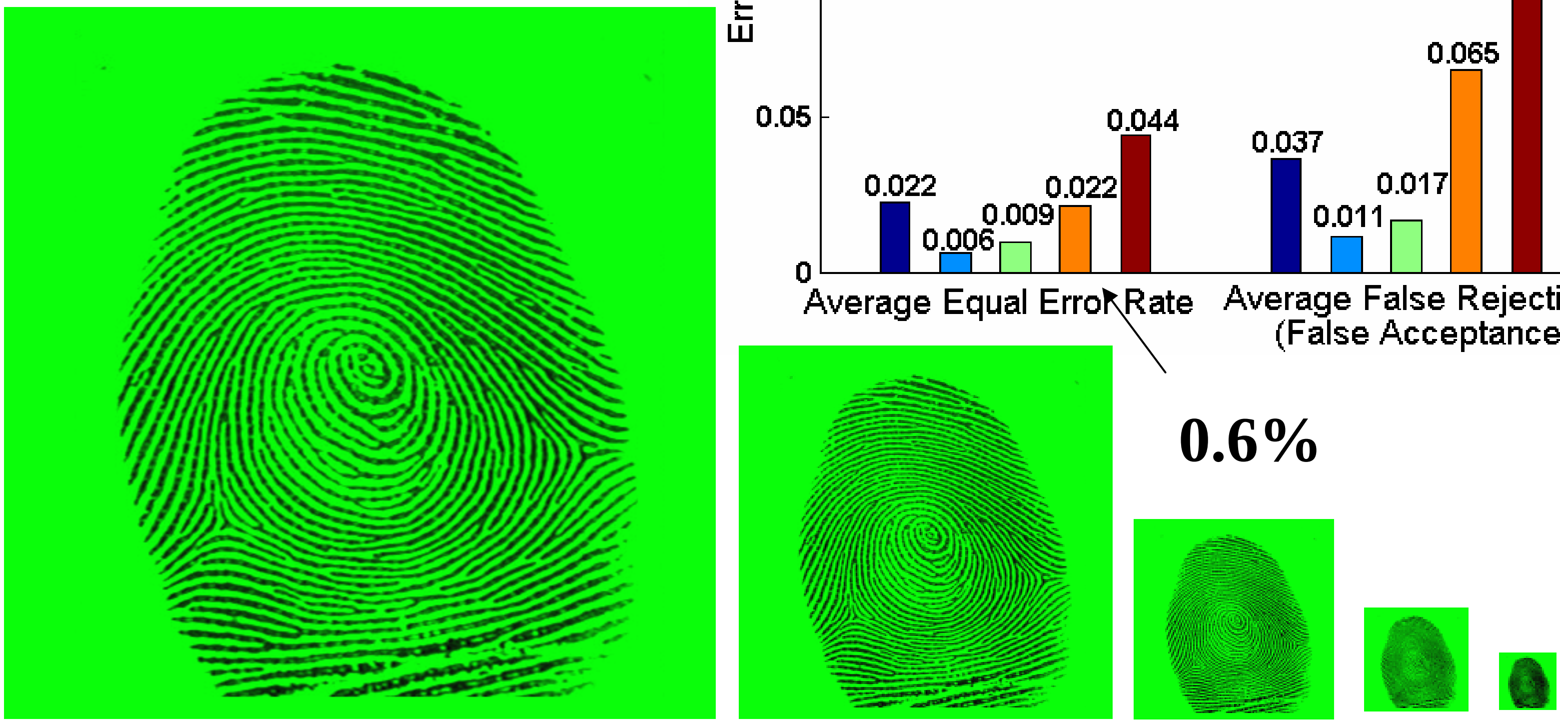
Resolution Effect



0.6%



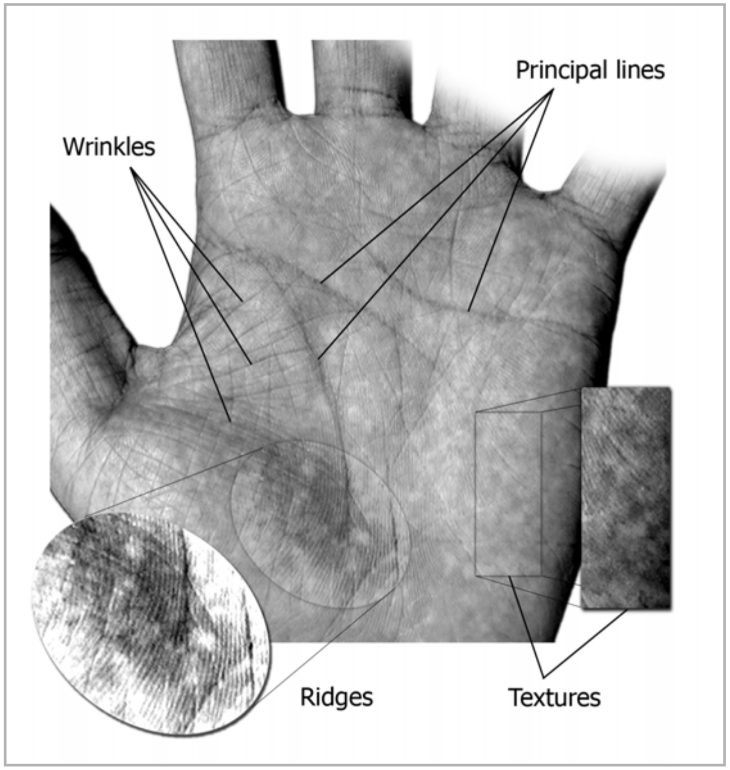
512x512 256x256 128x128 64x64 32x32

Electrical & Computer ENGINEERING

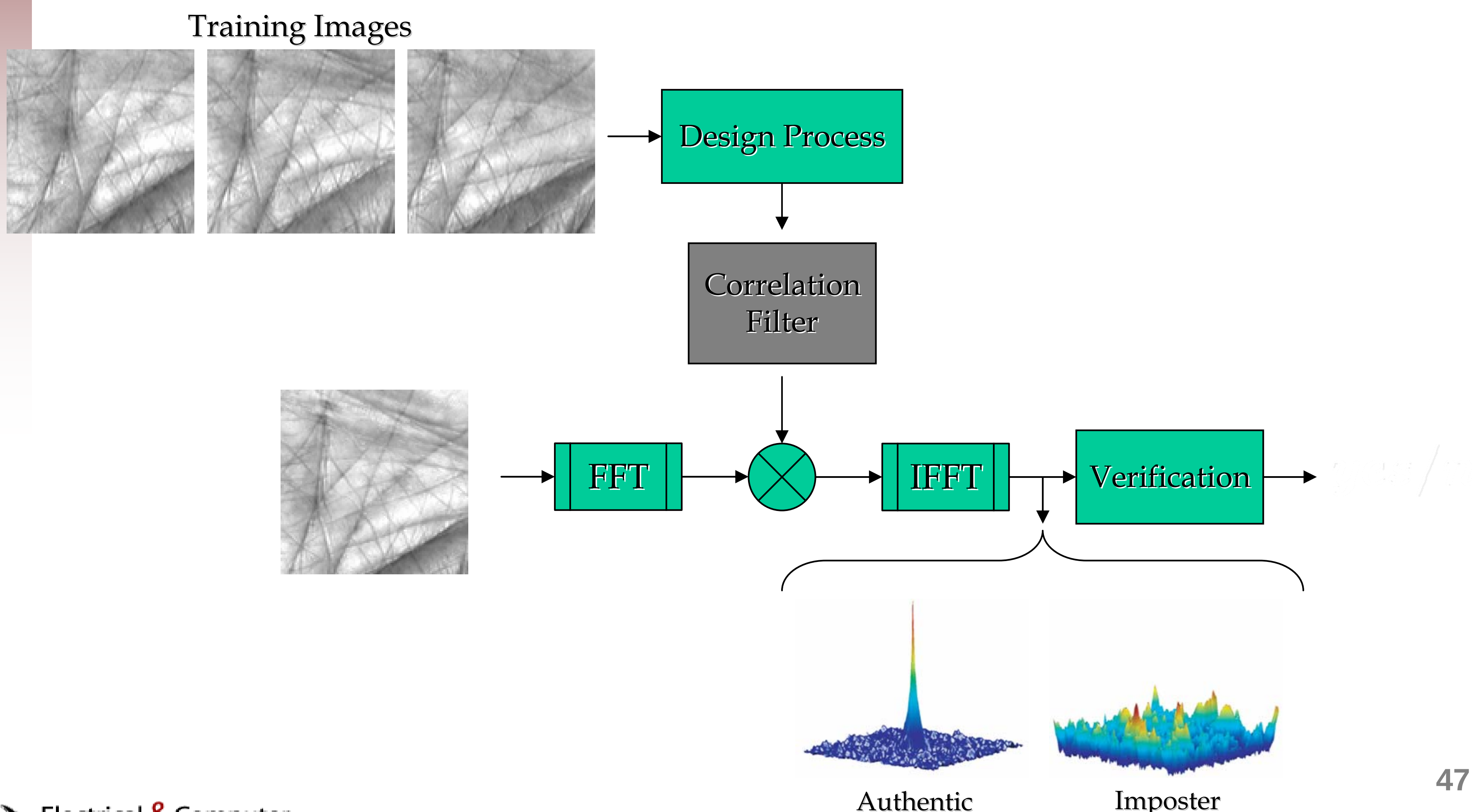
K. Venkataramani, B.V.K. Vijaya Kumar, "Fingerprint verification using correlation filters", *Audio- and Video- based Biometric Person Authentication (AVBPA)*, UK, 2003

Palmprints

- **Palmprints have a conglomerate of features.**
- **These include principal lines, smaller creases or wrinkles, fingerprint-like ridges and textures.**
- **Palmprints can be easily aligned about fiducial points of the hand's geometry or shape.**

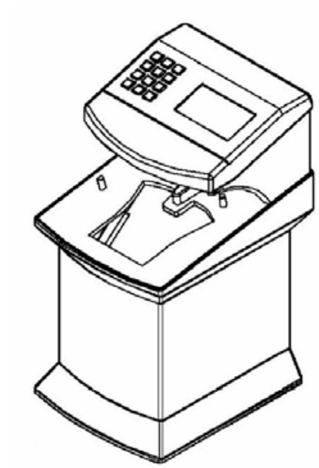


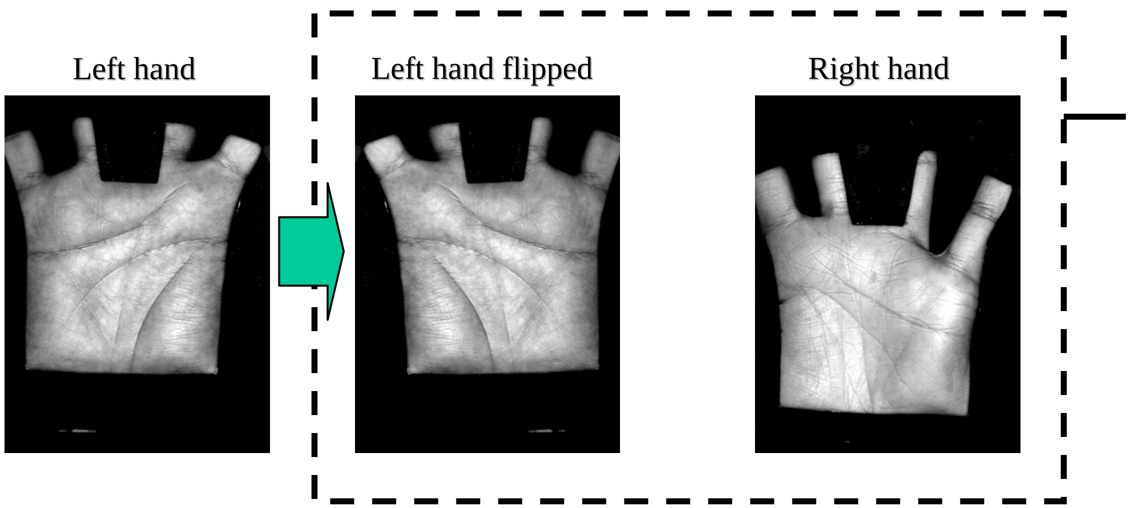
Palmprint Verification



Experiment Specifications

- *PolyU* **Palmprint Database**
- **100 palms (classes)**
- **Left hands flipped to look as right hands**
- **3 images per class for training**
- **3 images per class for testing**
- **5 different experiments using region sizes with sides of 64, 80, 96, 112, and 128 pixels**





Palmprint Verification Results

RESULTS OF OTSDF FILTER CLASSIFIER USING 100 CLASSES.

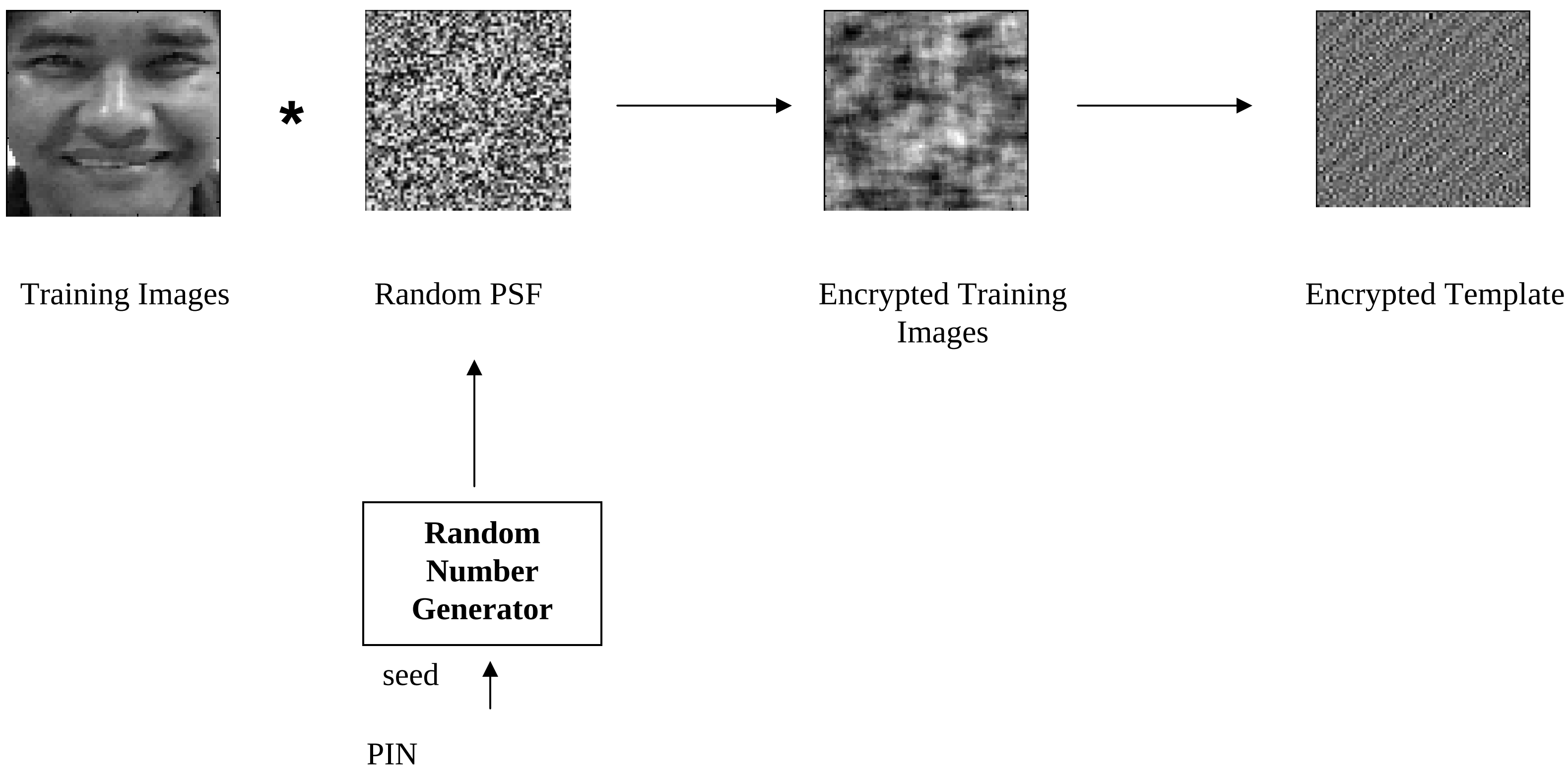
n	Avg FRRz (M_1)	Avg FARz (M_2)
64	2.6% (8)	0.07% (23)
80	1.0% (3)	0.02% (6)
96	0.3% (1)	0.01% (3)
112	1.0% (3)	0.01% (3)
128	0.3% (1)	0.03% (10)

Avg FRRz: Average FRR at zero FAR. M_1 misses out of 300.
Avg FARz: Average FAR at zero FRR. M_2 misses out of 29,700.

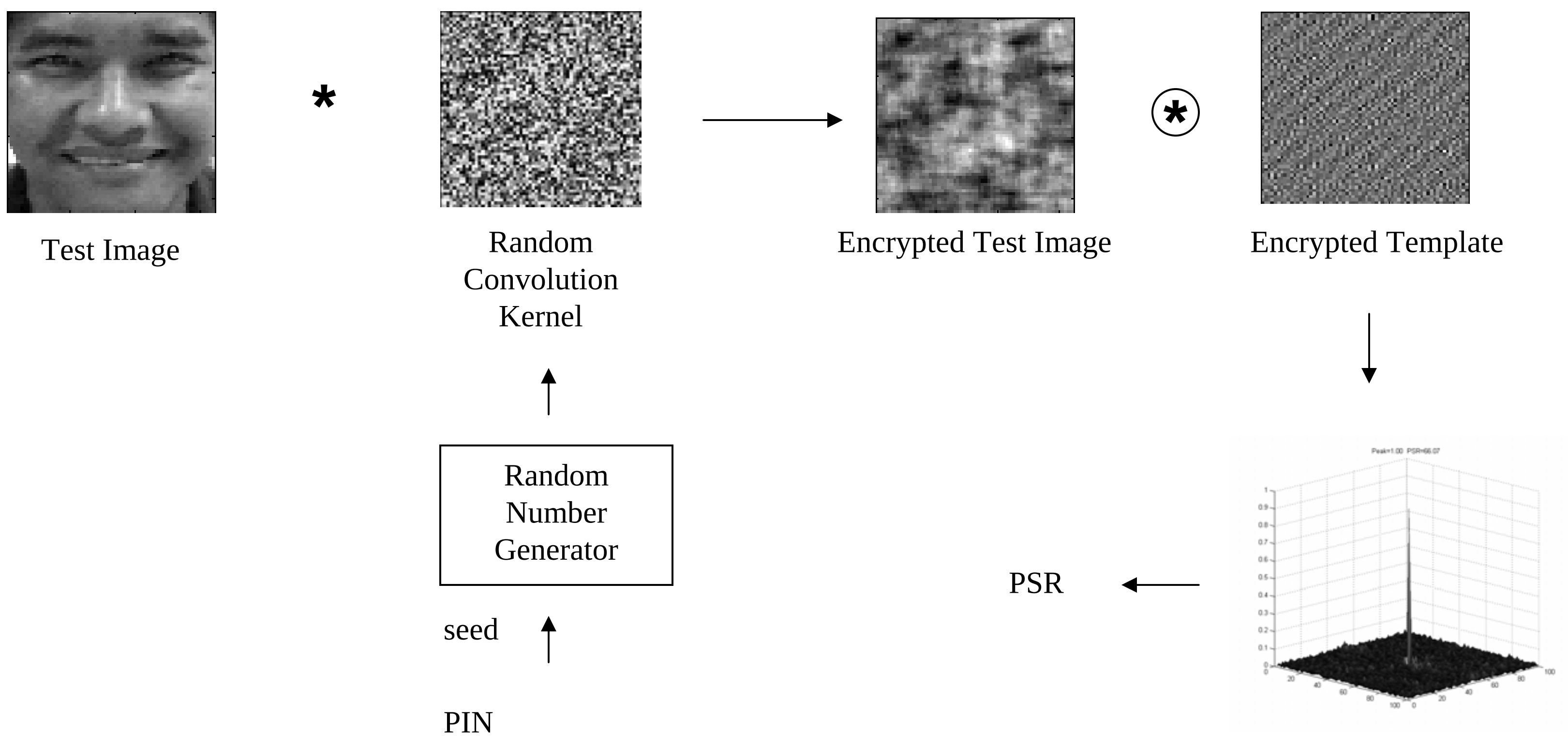
Cancellable Biometric Filters

- A biometric filter (stored on a card) can be lost or stolen
  - Can we reissue a different one (just as we reissue a different credit card)?
  - There are only a limited set of biometric images per person (e.g., only one face)
  - We have to figure out a way to encrypt them and ‘work’ or authenticate in the encrypted domain and NOT directly in the original biometric domain.

Enrollment Stage

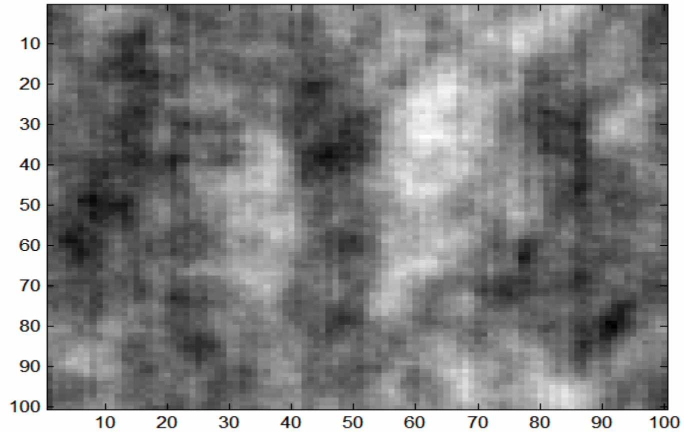


Authentication Stage

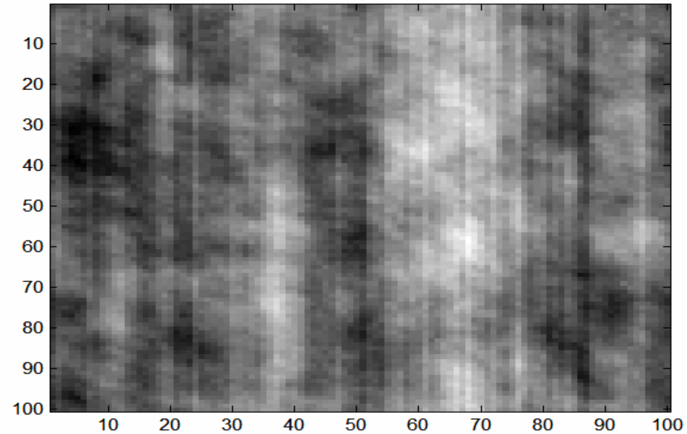


Example of Encrypted Images

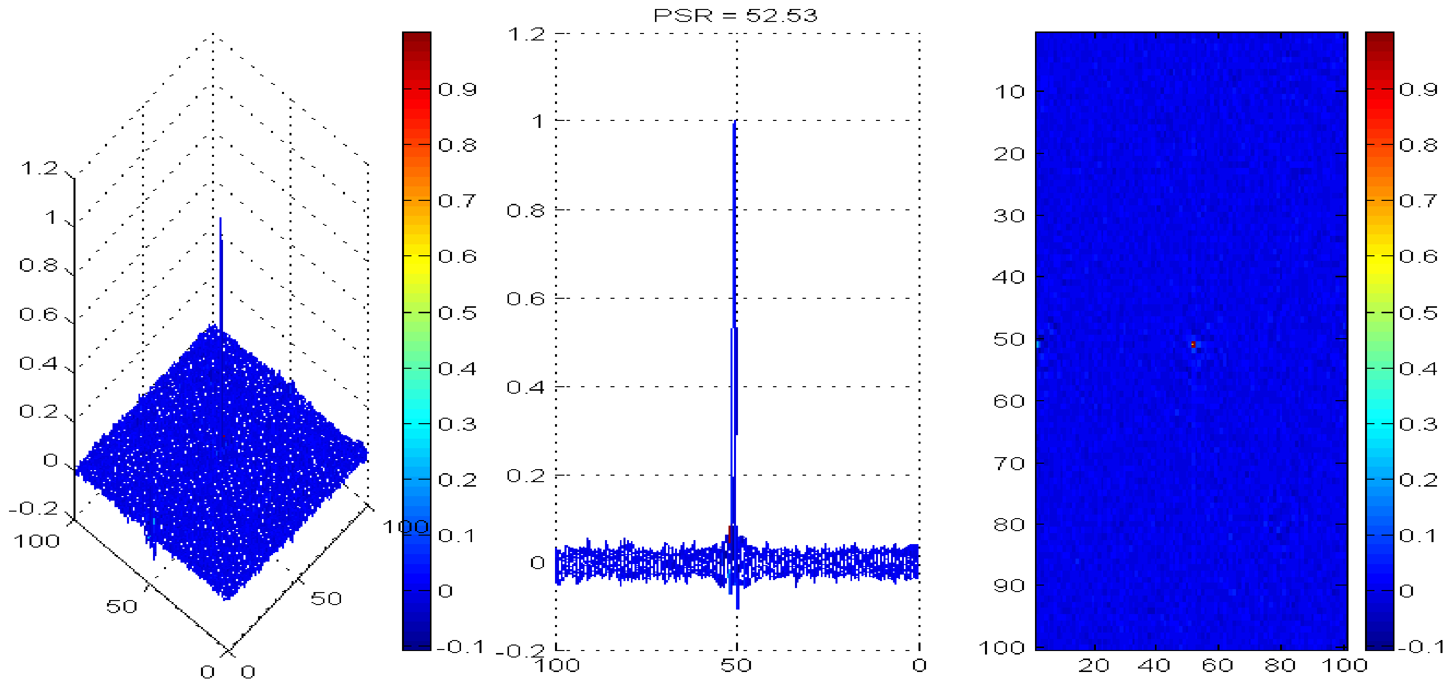
Authentic Person



Impostor Person



Correlation from an Authentic using Kernel 1



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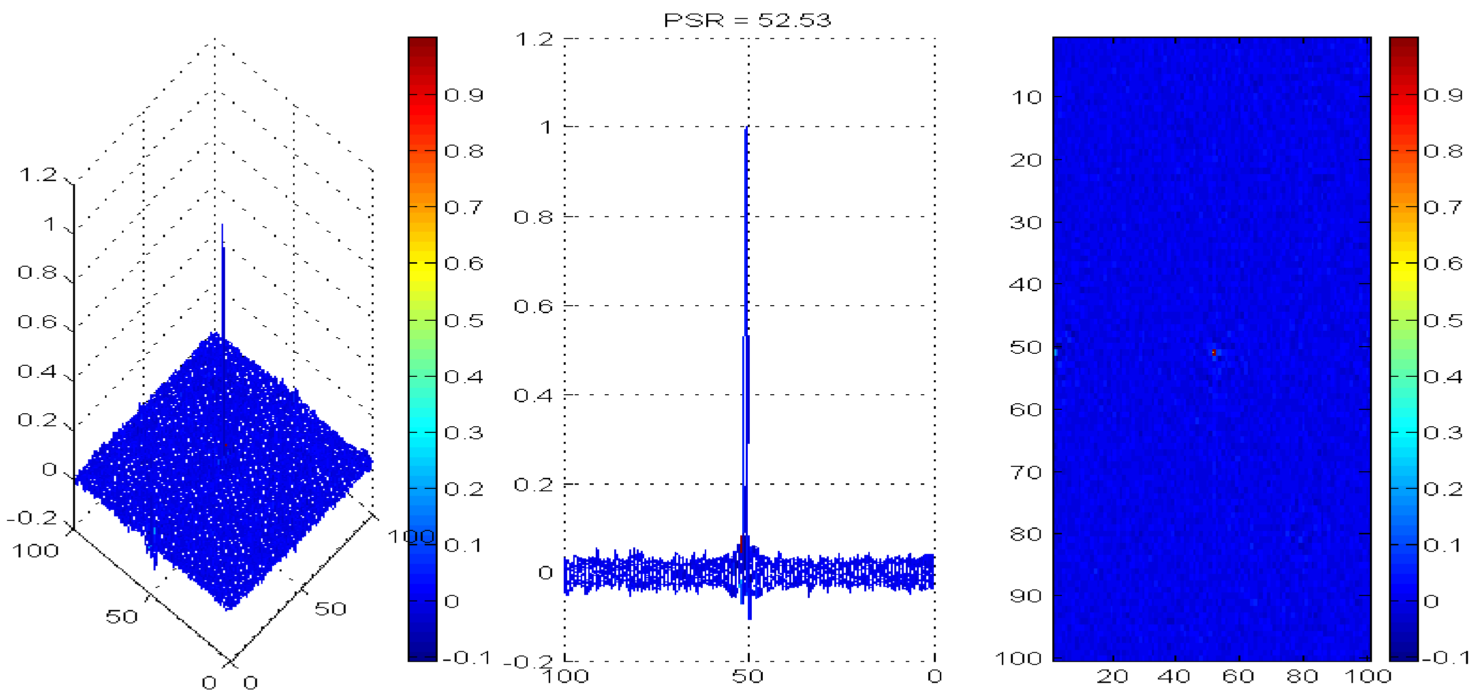
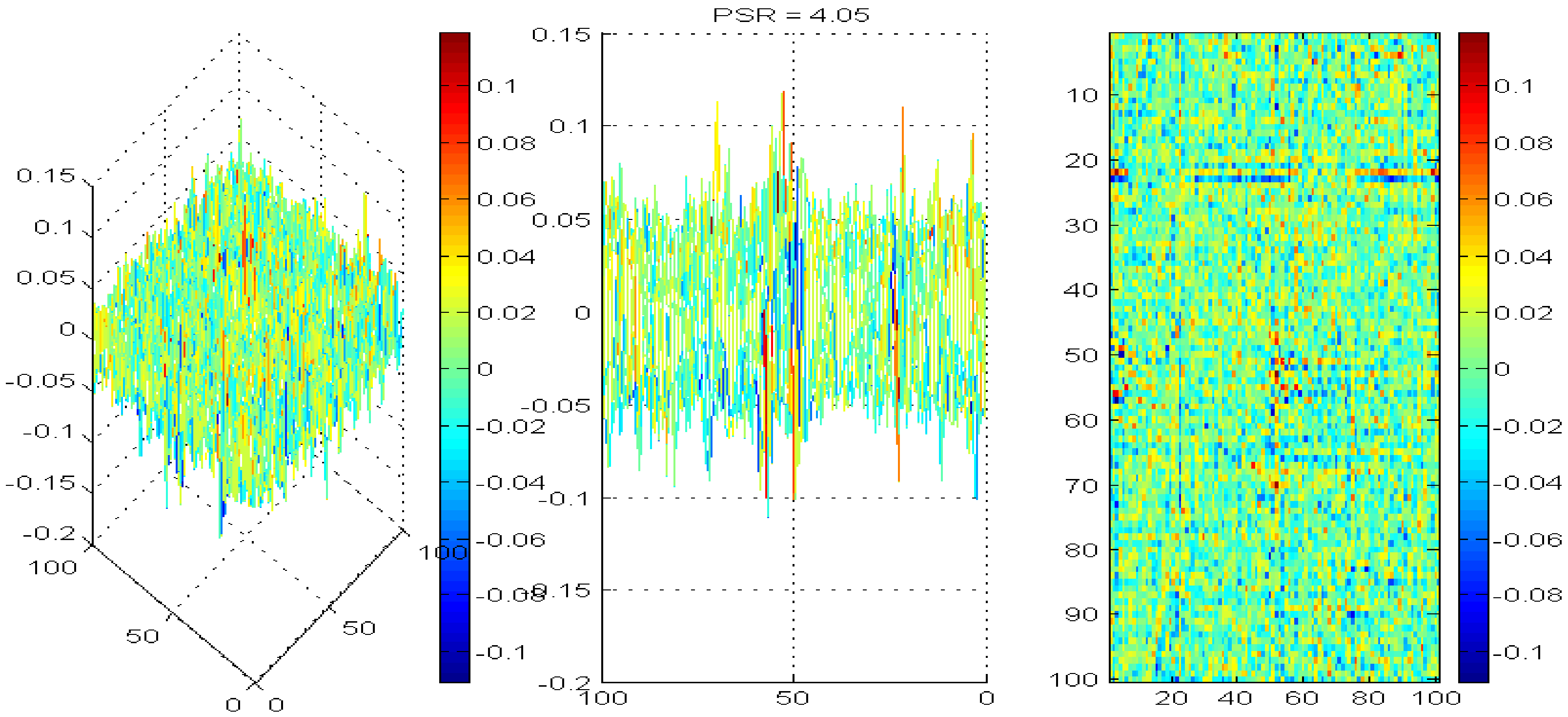
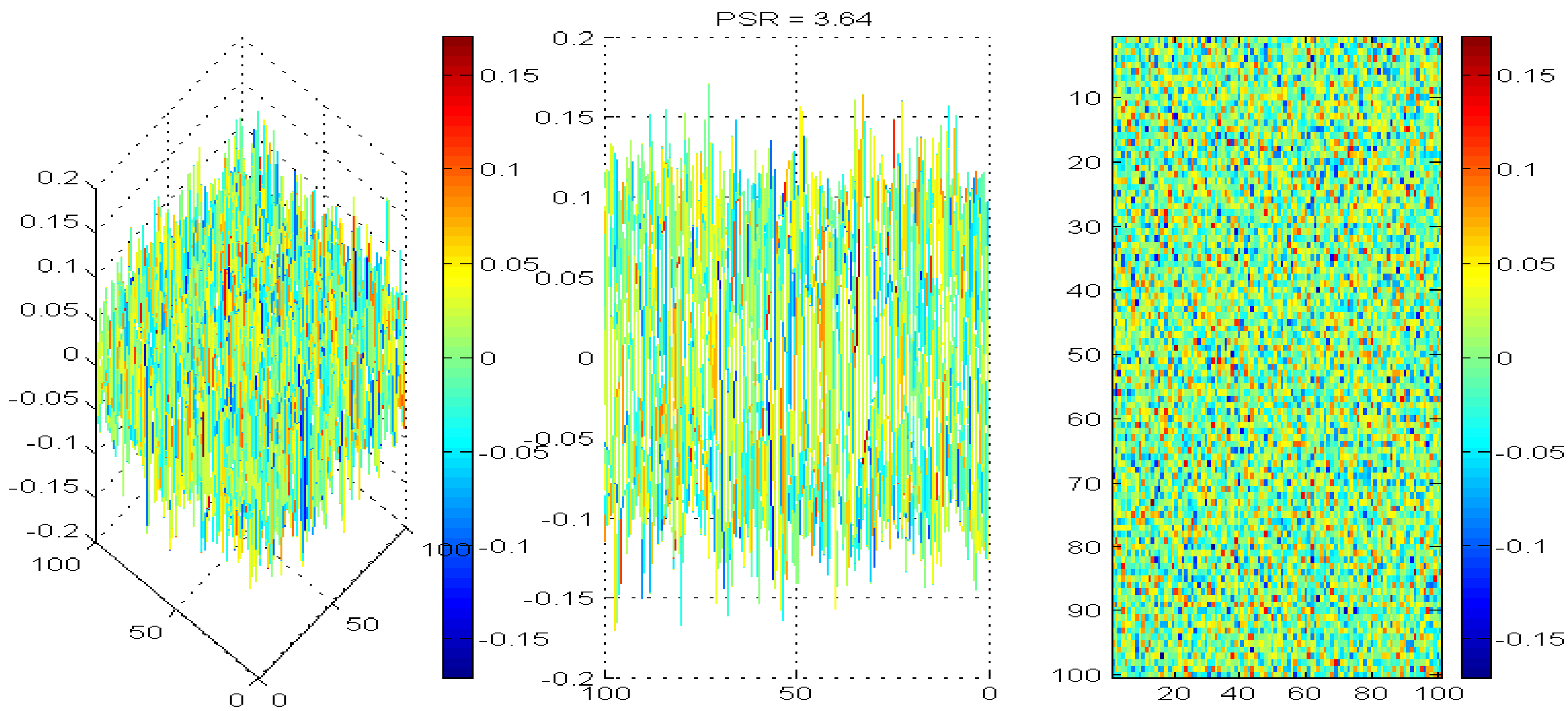
Correlation without Encryption



Correlation from an Impostor



Output from an Authentic using a Cancelled Kernel



Summary

- Correlation filters
  - Achieved excellent performance in face recognition grand challenge (FRGC)
  - Performed very well in iris challenge evaluation (ICE)
  - Also successful in fingerprint recognition and palmprint recognition
- All biometric modalities have their own strengths & weaknesses, suggesting that we may have to use multiple modalities in fielded systems
- Correlation filters provide a single matching engine for a variety of image biometrics --- making multi-biometric approaches feasible.